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A STUDY OF PILOT WHALES *(Globicephala macrorhynchus)* IN THE SOUTHERN CALIFORNIA BIGHT

by

William E. Evans, Jeanette A. Thomas and Donald B. Kent

ADMINISTRATIVE REPORT LJ-84-38C

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CONTENTS

	PAGE
INTRODUCTION	1
SURVEYS	1
METHODS	1
RESULTS	2
ACOUSTIC RESEARCH	2
METHODS	3
RESULTS AND DISCUSSIONS	5
SUMMARY	6
COLOR-PATTERN OBSERVATIONS	6
METHODS	7
RESULTS	8
DISCUSSION	8
ACKNOWLEDGEMENTS	9
LITERATURE CITED	10
APPENDIX I	33

LIST OF TABLES

Table		Page
1.	Results of flights to search for pilot whales, 1982	13
2.	Summary of published descriptions of pilot whale vocalizations	14
3.	Pilot whale sounds previously recorded	15
4.	Pilot whale acoustic sampling effort in 1982	16
5.	Background information with pilot whale recordings	17
6.	Relative proportion of the repertoire (and total number of vocalizations) for each vocalization category by pod of pilot whales	18
7.	Mean (and standard deviation) values for six parameters used to discriminate pod differences in whistles of pilot whales. F value indicates presence/absence of statistical difference as tested with a one-way analysis of variance. Pairwise comparisons were conducted using the Bonferroni test	19
8.	Contingency table analysis of the total number of vocalizations in three categories for three regions	20
9.	Mean (and standard deviation) for six parameters measured for whistles of pilot whales. Samples were lumped into three regions to statistically test for geographic differences using a one-way analysis of variance test. Pairwise comparisons were made using the Bonferroni test	21
10.	Dorsal color pattern type for 19 pods of pilot whales in the southern California Bight. Type A = no perceivable white, B = anterior-dorsal fin blaze plus post-dorsal saddle, and C = post-dorsal fin	22

LIST OF FIGURES

Figure		Page
1.	Relative density of pilot whales in the Southern California Bight as function of time of year (quarter), based on aerial surveys between January 1968 and April 1976. Modified from Leatherwood, et al., 1973.....	23
1a.	Observations of pilot whales in study area by quarter. From Leatherwood et al., 1973.....	24
1b.	Observations of pilot whales in study area by quarter. From Leatherwood et al., 1973.....	25
2.	The Southern California Bight, showing areas of known concentrations of pilot whales, in which aerial and boat searches were made.....	26
3.	Aerial survey effort. The number of times each 10X10 minute block was surveyed is given.....	27
4.	Sightings of pilot whales during aerial (o) and vessel (●) surveys.....	28
5.	Vessel survey effort. The number of times each 10X10 minute block was surveyed is given.....	29
6.	Terminology used to describe the color pattern of pilot whales	30
7.	Three color pattern types scored for pilot whales in this study. A. No perceivable white, B. anterior-dorsal fin stripes and post-dorsal fin saddle, and C. post-dorsal fin saddle.....	31
8.	The form used in the field.....	32

INTRODUCTION

Pilot whales (Globicephala spp.) have been found year-round in the Southern California Bight; their numbers usually increase dramatically in winter. Leatherwood et al. (1973) found, in more than 24,000 nm of aerial surveys of the Southern California Bight between January 1968 and April 1976, that numbers were significantly higher in Quarters IV (October, November and December) and I (January, February and March). (See Fig. 1, 1a, 1b). From those data, detailed observations from shipboard, knowledge of the species' feeding habits, and consideration of the distribution of their principal prey species, (Loligo opalescens), they hypothesized that there were "resident" pilot whales in the Bight whose ranks are augmented during the squid spawning season (Fields, 1965) by immigrants from undetermined areas.

Dohl et al. (1978) reviewed previous work (excluding the above account) and reported on their own aerial and ship surveys between May 1975 and March 1978. They concluded independently that "there appears to be a resident population around the Santa Catalina Island - San Pedro escarpment area. During winter months the Southern California Bight population numbers increase, as does the distribution of the animals throughout the area."

It has been suggested that the expanded winter population indicates the presence of a second species, the long-finned pilot whale (Globicephala melaena), as might have been the case historically in coastal waters of Japan (Kasuya, 1975) or perhaps a second breeding stock of G. macrorhynchus which emigrates to the Southern California Bight during winter and spring, perhaps in pursuit of squid.

Past work had indicated that some populations of cetaceans can be separated by: 1) differences in vocalization patterns and structure and, 2) differences in pigmentation patterns (Winn and Olla 1979, Evans and Yablokov, 1983; Leatherwood et al., 1973). The present study was designed to determine whether the existence of two distinct groups of pilot whales could be documented by acoustic differences or differences in external coloration.

I. SURVEYS

METHODS

Because the aerial surveys made under this study were designed only to assist the vessel in locating groups of pilot whales, no random or systematic searches of the entire Bight were conducted; rather, flights proceeded directly to localities of known concentrations of the whales (Fig. 2). Once a pod was located, observers counted the animals, documented color pattern, recorded sound, and noted behavior.

Searches were made from either a twin-engine Travellaire or a twin-engine Aztec flying at altitudes of 750 to 1200 feet, depending on visibility. From 1 to 3 observers and the pilot searched for whales along the entire track. The aircraft lingered in areas of known concentrations to maximize the probability of sighting. If the vessel was within range, it was summoned by radio; when it arrived, the aircraft resumed its search or returned to the airfield.

RESULTS

In 8 flights (25 flight hours) 8 pods of pilot whales, containing an estimated 185 individuals, were sighted (Table 1). The aerial survey effort, expressed as number of times each block (10-minutes of latitude by 10 minutes of longitude) was surveyed, is summarized in Fig. 3. The locations of all pilot whale sightings are shown in Fig. 4. Vessel survey effort within the Southern California Bight is shown as number of times each 10-minute block was effectively surveyed (Fig. 5).

II. ACOUSTIC RESEARCH

We hypothesized that different groups (species, races, and perhaps even "super herds") would be expected to have different vocalizations or produce specific vocalizations at different rates. If such differences could be demonstrated, they could be used to monitor seasonal movements of pilot whales in the Bight and elsewhere in the Pacific.

Using a biological variable to discriminate between breeding stocks of animals requires that the parameters: 1) can be quantified, and 2) reflect something related to the breeding biology of the animal. Selecting specific vocalizations that are related to breeding requires information about the functions of the sounds. It is very difficult to determine the specific features of a sound that are most likely to exhibit differences from stock to stock; features often are selected for the convenience of measurement and analysis techniques.

We found 8 published descriptions of pilot whale vocalizations (Table 2). The large number of sound types named and described presumably results from: 1) high individual variability in sound production, 2) grading of one sound into another, 3) subjective classification, 4) inconsistent scoring of two simultaneous vocalizations as separate or together, and 5) variable repetition rate of pulses, ranging from click trains to buzzes.

To document geographic differences, Taruski (1976) examined whistles of pilot whales from: 1) Nova Scotia, Newfoundland, Nantucket, and the Mediterranean (which he assumed were Globicephala melaena), and 2) the West Indies, Peru, and California (which he assumed were G. macrorhynchus). The Mediterranian signals were recorded by Busnel and Dziedzic (1966) and later were identified as G. macrorhynchus by Evans (1967). For whistles from each site, Taruski (1976) compared the mean duration, mean frequency, and contour type (level, falling, rising, up-down, down-up, multiple hump, or wavering). Significant differences between the assumed G. melaena and G. macrorhynchus were demonstrated only for mean whistle duration; the

whistles of G. melaena were consistently longer. This is contrary to the conclusions of Schevill and Watkins (1964). In addition, within the G. melaena sites (Newfoundland and Nova Scotia), the "northern dialect" was characterized by whistles of lower mean frequency and longer mean duration than the "southern dialect" of G. melaena (Schevill and Watkins, 1964).

It is difficult to compare vocalizations among pods, regions, or species when the vocal repertoire has been classified by many investigators into different categories. If differences occur they should be sufficiently distinct to be indicated by a few simple measurements of an easily classified sound.

The objectives of our acoustic study were to:

1. measure the variability in spectral and temporal characteristics of whistles sampled from different pods in the Southern California Bight.

2. measure the variability in spectral and temporal characteristics of whistles sampled from the mainland California coast, Channel Islands, and eastern tropical Pacific, and

3. evaluate the usefulness of variations in whistles for distinguishing breeding stocks of pilot whales.

METHODS

Vocalization data were obtained by analyzing our existing recordings of eastern Pacific pilot whales (Table 3) and 9 recordings that we made during 7 cruises along the Southern California mainland and Channel Islands during 1982 (Table 4). We made underwater recordings of pilot whales using a Racal Store 4-channel tape recorder (frequency response 300 Hz to 300 kHz $\pm$ 3dB, at 15.24 cm/sec) and a Bruel and Kjaer 8103 hydrophone (frequency response 1 Hz to 200 kHz). Recordings were made from shipboard when animals were in visual range. The recordings with most vocalizations were obtained at night when the boat was anchored near squid fishing grounds where pilot whales were heard most of the night.

For analysis, we assumed that each recording represented a different pod of pilot whales. A description of each pod (pod size, behavior of the animals, time of day, and associated marine mammals) appears in Table 5. The 9 recordings were divided into three regions: 1) mainland California coast - samples taken within 5 miles of the shoreline in the Southern California Bight, 2) Channel Islands - samples taken near any of these islands, and 3) eastern tropical Pacific - pelagic samples taken in the eastern tropical Pacific on a transect between Manzanillo, Mexico and the Hawaiian Islands.

Sonagrams (time versus frequency displays) of all vocalizations were made using a Kay 6041B Sona-Graph set at the 16 kHz scale using a narrowband setting or using a Unigon SC101 realtime sonagram analyzer. The entire frequency range of recordings was analyzed, but most sounds were detected under 20 kHz. For the present study, we did not name vocalizations or fit them into existing categories. Instead, vocalizations were classified into the following types:

1. Whistles: long duration tonal vocalizations, having no harmonics; sometimes ascending, sometimes descending, and sometimes constant in frequency.

2. Frequency-modulated (FM) sweeps: long duration sounds often with harmonics, often characterized by abrupt changes in frequency; sometimes ascending, and sometimes descending.

3. Pulses: short narrow-band click trains or buzzes of variable repetition rate.

For each vocalization type, the number of occurrences per recording and the relative proportion of the repertoire were calculated (Table 6). Data for pods and regions were tested for statistical differences using a contingency table analysis ($p < 0.05$).

Because whistles were the most common vocalization and identified by Taruski (1976) as a good indicator of geographic variation, we measured the variability in 6 parameters of whistles:

1. duration (total length in seconds),

2. start frequency (frequency in kHz at the initial portion of the sound),

3. end frequency (frequency in kHz at the termination of the sound,

4. maximum frequency (highest frequency in kHz exhibited during the sound),

5. minimum frequency (lowest frequency in kHz exhibited during the sound),

6. sweep frequency (maximum change in the dominant frequency, or maximum frequency minus the minimum frequency).

One-way analysis of variance tests (ANOVA) with comparisons of treatment means, using Bonferroni's test, were performed to determine which of these parameters were significantly different for each pod and each region.

RESULTS AND DISCUSSION

Appendix I contains selected sonagrams of pilot whale vocalizations from different pods and regions. All vocalizations were assumed to be from short-finned pilot whales, Globicephala macrorhynchus. Variability within vocal types was high. Table 6 illustrates the relative proportion of whistles, frequency-modulated sweeps, and pulses used by each pod. The most extensive use of pulses was by pods E-G, which were actively feeding on squid. Such pulses, click trains and buzzes probably are associated with echolocation and detection of food at night. In samples B, C, D, and I pilot whales were swimming past the ship and no pulses were detected. Because pulses were recorded primarily during feeding, we do not feel that they are suitable for discriminating geographic or taxonomic variation in pilot whales.

The use of FM sweeps was highest (47% of total sounds) in recordings of pod A. These animals had just been captured and apparently were communicating with nearby pod members. FM sweeps were lowest (0%) in pods B and I, which were slowly swimming past the ship when recorded. In other pods, FM sweeps comprised from 12% to 37% of the repertoire. In all these latter instances, behavior included some degree of social interaction, e.g. milling, group feeding. FM sweeps probably have a social context and may be suitable for discriminating geographic or taxonomic variation in pilot whales. The problems with using them lie in their complex nature and in determining which of many parameters should be measured and compared.

Whistles, because of their simple, non-harmonic acoustic properties, lend themselves to measurement of discrete characteristics for geographic and taxonomic comparisons. Except in the case of the captured pilot whale (Pod A), whistles were always the most common sound. In two cases, (pods B and I) whistles were the only vocalization detected. The number of whistles was high whether the animals were feeding, interacting, or swimming. Perhaps, as reported for other odontocetes (Lagenorhynchus obliquidens and Stenella plagiodon) by Caldwell et al. (1971; 1973), pilot whale whistles are signature vocalizations conveying an animal's identity. If so, they would be expected to be used in a variety of behavioral contexts and to exhibit high variability. The most difficult problem in analyzing whistles is characterizing their variability and whether it is related to individual, pod, breeding stock, or species.

Table 7 shows the results of a one-way ANOVA test and of pair-wise comparisons of treatment means for six parameters of whistles measured for each pilot whale pod. Statistically significant differences were detected for all parameters and between most pods. The high standard deviation in most categories implies that at least some of the variability in whistles may be related to individual differences. Between-pod variability exists, but it is not bracketed to a specific pod and there is a great deal of overlap in the ranges of frequency and duration among pods. All samples were from a single exposure to a pod. To determine whether whistles can be used to describe a specific pod, long-term studies on the acoustic behavior of a specific pod must be conducted.

Contingency table analysis of the total number of whistles, FM sweeps, and pulses by region ($X^2 = 75.15$) showed that the three regions in the Pacific are significantly different (Table 8). However, since these call types appear to be highly correlated with behavior, e.g., feeding, distinguishing regional differences on the basis of vocalization types is not supported.

Spectral and temporal characteristics of whistles by region were compared using a one-way ANOVA test and pair-wise comparisons (Table 9). Only total duration, start frequency, and sweep frequency were statistically different among regions. Specifically, whistles in the eastern tropical Pacific were shorter than those recorded near the Channel Islands. Whistles from the mainland California coast started at statistically lower frequencies than whistles from either the Channel Islands or the eastern tropical Pacific. Sweep frequency was greater in the eastern tropical Pacific than at the Channel Islands. Like Taruski (1976), we found that whistle duration is most useful in characterizing geographic differences.

SUMMARY

1. The relative proportion of whistles, FM sweeps, and pulses was significantly different among pods, and usage was related to the function of the sound or behavior of the animals in the pod at the time of the recording.

2. No differences in the relative proportion of whistles, FM sweeps, and pulses was found between samples from the 3 regions.

3. The recordings (assumed to be from 9 pods) had significantly different temporal and spectral characteristics in their whistles.

4. The amount of individual variation in vocalization characteristics was not tested, but because of the large standard deviations in measuring 6 characteristics, it is suspected to be high.

5. Detailed measurements of whistles from the three regions of the Pacific showed that: a) they were shorter in the eastern tropical Pacific than in the Channel Islands, b) California coastal whistles had the lowest starting frequency, and c) sweep frequency in the eastern tropical Pacific was higher than at the Channel Islands.

III. COLOR-PATTERN OBSERVATIONS

The distinction between the two accepted species of pilot whales, the short-finned pilot whale (Globicephala macrorhynchus) and the long-finned pilot whale (G. melaena), is based primarily on differences in skull morphology (van Bree, 1971; Kasuya, 1975 and Polisini, 1980). Skulls of Southern California Bight specimens examined by Polisini (1980) were all G. macrorhynchus. In general, G. macrorhynchus inhabits tropical and subtropical areas of the Atlantic and Pacific Oceans and G. melaena inhabits cold water areas of the North Atlantic and the southern hemisphere (Davies, 1963). There is some evidence that the two species have overlapping ranges, e.g., in the Cape region of South Africa (van Bree et al., 1978) and in Japan (Kasuya, 1975).

These two species also have been described as having different external coloration. Both are predominantly black on the dorsal surface and flanks, with a white throat-chevron and genital patch on the ventral surface. G. melaena displays a white to light-gray post dorsal fin saddle; this post-dorsal fin saddle is indistinct in some specimens of G. macrorhynchus observed in tropical and warm temperate waters (c.f. photograph, pp. 514-515, Linehan, 1979).

In the northeastern Pacific, some individuals and pods of pilot whales display vivid white post-dorsal fin saddles. In addition, prominent white to light-gray stripes extending from the anterior insertion of the dorsal fin forward to the blowhole are present in some individuals (Evans and Yablokov 1983; Leatherwood et al., 1982, figs. 155, 158). Markings similar to those have been described by Yonekura et al. (1980) in G. macrorhynchus from waters off Japan. The anterior position of the stripes, when viewed laterally, give the appearance of white eye patches, similar to those of G. melaena edwardii in the southern hemisphere (Davies, 1970).

Given the demonstrated variability of coloration within other species of delphinids (e.g. Stenella spp., Delphinus delphis, and Orcinus orca), color pattern probably is not a valid taxonomic character (Mitchell, 1970; Perrin 1972; Evans 1975). However, variability in color pattern has been used to differentiate regional stocks or populations.

In 1977, W. E. Evans and A. V. Yablokov initiated a study to determine the variability in the color pattern of several delphinids from the northeastern Pacific, including Globicephala macrorhynchus. Photographs of pilot whales (still, movie, and video) were taken at sea from ships and aircraft, and of captive individuals on display at several oceanaria. Examination of approximately 475 individuals revealed that dorsal coloration ranged from no perceivable white to a grayish or white post-dorsal fin saddle and dorsal stripes. Based on the observed variability in pilot whale color pattern, Evans hypothesized that the "in-shore, resident" pods could be discriminated from the "off-shore, migrant" pods on the basis of their color pattern.

METHODS

To test that hypothesis, we scored photographs of Globicephala taken in the Southern California Bight during seasons of low and high abundance. Figure 6 illustrates the terminology used. Dorsal color patterns were divided into three categories: A) no perceivable white, B) white stripes extending from the dorsal fin to the blowhole and a distinctive post-dorsal fin saddle, or C) only a post-dorsal fin saddle (Fig. 7).

Data were collected in the field by observers scoring on the form shown in Fig. 8; when possible, corresponding black and white 35 mm photographs were taken. During 5 cruises conducted in 1982, 7 pods were sampled. The data were supplemented with video footage taken during the 1982 summer cruise of the R/V David Starr Jordan in the eastern tropical Pacific (provided by Rennie Holt of NMFS) and with data from 8 cruises conducted in the Southern California Bight prior to 1 January 1980. During a total of 15 cruises within or adjacent to the Southern California Bight 19 pods, representing

approximately 270-314 individuals, were sampled (Table 10). Four pods were encountered in the winter quarter, 3 in the spring, 6 in the summer and 6 in the fall. In addition to these field data, the color pattern was documented for 7 individuals on display at Southern California oceanaria: 1 specimen at Marine World/Africa USA, 1 at Marineland of the Pacific,and 5 at Sea World, San Diego; all were collected within the Southern California Bight in the fall or winter quarters.

RESULTS

The 19 pods were classified as color pattern type A, B, or C when sighted in the field (Table 10). Twelve were scored as predominantly B type; 3 were mixed, with gradations from B to C type, and 4 were judged as C type (Fig. 8). No type A or melanistic animals were observed. Upon closer examination, many photographs originally scored as type C were rescored as type B. Careful examination of the 6 captive specimens indicated that all were of the B type pattern. However, if these captive animals had been scored at sea or from a photograph, 3 would have been classified as A type and 3 would have been scored as C type, since the patterns were present, but almost imperceptible except at at close range.

Although not quantified in this study, we believe, on the basis of observations of captive animals, that the intensity of expression of the dorsal fin saddle, the dorsal stripes and the ventral breast-chevron vary in the same individual as a function of time and or environmental condition. A female pilot whale held by Marineland of the Pacific since September 1966 has displayed all three color pattern types during her 18 years in captivity.

Since the color pattern under study is dorsal, the viewing angle is critical to interpreting the type. The highest quality data were collected when the observer or camera angle relative to the subject was 45° or greater. At lower angles the observer or camera had a lateral view and the anterior-dorsal fin blaze was more difficult to detect (see Fig. 6). Selected photographs in Appendix II show the differences in color pattern when photographs were taken at an angle >45° or at an angle <45°.

When the distribution of color pattern types in the four quarters of the year was examined using a 3 x 4 contingency table analysis (<0.05), no significant seasonal differences in pattern type were detected ($X^2 = 6.57$, df = 6).

DISCUSSION

In the eastern tropical Pacific usually no, or only faint, white markings on the dorsal surface of Globicephala macrorhynchus are perceptible. The observation that all of the captive G. macrorhynchus displayed all components of the pilot whale color patterns (illustrated in Fig. 6) in a range from barely perceptible to highly visible indicates that we have probably been scoring degrees of expression of a pattern and not presence or absence of a pattern type. If degrees of expression are environmentally, rather than genetically, controlled, it is not a valid character for differentiating stocks or populations.

If additional data are collected to address this problem, we recommend quality aerial photography, because a larger percentage of the pod can be seen. Within-pod variation and individual differences are easier to document. This is well illustrated by the photographs presented in Leatherwood et al. (1982, pp. 124-128) and in Appendix II.

Although there is a suggestion of acoustic differences between pods of pilot whales in the Southern California Bight, the increased numbers in winter and spring may only be apparent. In those seasons, Fields (1965) found all pilot whales clustered in squid spawning areas, mostly at the heads of deep submarine canyons and Hui (1977), examining the data of Leatherwood et al. (1973), discerned a significant tendency for the whales to distribute over escarpments and sea mounts, rather than over basins and plains. It is possible that in summer and fall the pilot whales are scattered throughout the Bight and that they are concentrated in winter and spring as a result of the seasonality of spawning of the squid, giving the appearance of expanded numbers. Only intensive and detailed surveys to estimate population numbers as a function of season can resolve this problem.

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Table 1. Results of flights to search for pilot whales, 1982.

Quarter	Date	Cruise supported see Table 2	Number of pods	Number of individuals seen
I	4 Jan	-	1	25
	11 Jan	A	0	0
	12 Jan	A	0	0
	13 Jan	A	0	0
	23 Jan	B	2	21
II	30 Apr	C	1	20
	16 June	-	3	19
III	-	-	-	-
IV	9 Nov	G	1	100
TOTAL			8	185

Table 2. Summary of published descriptions of pilot whale vocalizations.

Description of Vocalization	Source							
	Kellogg (1940)	Kritzler (1949)	Norris & Prescott (1961)	Schevill & Watkins (1964)	Busnel & Dziedzic (1966)	Taruski (1976)	Dreher (1966)	Thompson & Friedl (1982)
- roaring	+							
- high pitched whistle		+						
- baby cry		+						
- pulsed sound resembling a rusty hinge		+						
- popping sound		+	+					
- loud smacking of blow hole		+						
- chirping sound			+					
- high pitched squeak			+					
- whistles					+			
- squeals				+	+	+	+	
- whistle and pulse				+				
- creaking					+			
- blast					+			
- Fm whistle and creak					+			
- creak and whistle					+			
- boing						+		+
- very long whistle					+			
- thumps								+

ble 3. Pilot whale sounds previously recorded.

gion	Pod Designation	Date	Latitude	Longitude	Site	Researcher
stern opical cific	A	30 March 1965	21°55'N	158°40'W	Wainai-Pokai Bay, Hawaii	W. E. Evans
	B	20 June 1982	12°47'N	120°48'W	eastern tropical Pacific	J. A. Thomas
	C	19 June 1982	10°52'N	117°52'W	eastern tropical Pacific	J. A. Thomas
	D	11 June 1982	6°43'N	105°43'W	eastern tropical Pacific	J. A. Thomas
annel slands	E	February 1977	32°45'N	118°20'W	San Clemente Island	W. E. Evans
	F	10 December 1980	33°20'N	118°29'W	Silver Canyon, Santa Catalina Island	J. A. Thomas
	G	12 January 1982	33°25'N	118°31'W	Catalina Harbor, Santa Catalina Island	J. A. Thomas
ainland oastal alifornia	H	August 1962	33°35'N	118°10'W	San Pedro, California	W. E. Evans
	I	10 October 1980	32°46'N	117°20'W	La Jolla Canyon, California	J. A. Thomas

Table 4. Pilot whale acoustic sampling effort in 1982.

Vessel	Beginning Date	Ending Date	Number of Encounters	Number of Recordings	Vocalizations heard
R/V Bomar	7 Jan 1982	15 Jan 1982	2	1	+
R/V Sea Bass	21 Jan 1982	21 Jan 1982	1	1	-
R/V Laura C	20 Apr 1982	22 Apr 1982	3	3	-
R/V Laura C	15 Aug 1982	15 Aug 1982	1	1	-
R/V Sea World	20 Oct 1982	20 Oct 1982	0	0	-
R/V David Star Jordan	11 June 1982	5 July 1982	6	3	+++
R/V Sea World	periodic in October/November		3	0	-

Table 5. Background information with pilot whale recordings.

Region	Pod Designation (see Table 2)	Approximate number of animals	Associated with other species	Description of Behavior	Time
eastern tropical Pacific	A	7-12	None	Animal recorded after capture and while secured alongside a boat; other animals swimming past ship.	early morning
	B	3-5	None	Swimming past ship.	1800
	C	1-3	None	Swimming past ship.	0820
	D	15-20	Pseudorca crassidens & Grampus griseus sighted 10 min. later	Swimming past ship; slow milling in front of ship when ship stopped.	0945
Channel Islands	E	a. 15	None	One large male with several females; stationary group, slow milling.	daytime
		b. 20	Tursiops truncatus	Moving slowly along shoreline of island.	daytime
	F	40*	Zalophus californianus	Animals feeding next to anchored squid fishing boats.	night time
	G	50*	Zalophus californianus	Animals feeding next to anchored squid fishing boats.	night time
mainland coastal California	H	8-10	None	Milling, then slowly moving away from boat.	day time
	I	3-8	Tursiops truncatus sighted 20 min. later	Swimming past boat.	morning

* The number of animals is difficult to estimate in the dark.

Table 6. Relative proportion of the repertoire (and total number of vocalizations) for each vocalization category by pod of pilot whales.

Region	Pod Designation	Relative Proportion of Repertoire (Number of Vocalizations) Whistle	Fm Sweeps	Pulses
eastern	A	45% (17)	47% (18)	8% (3)
tropical	B	100% (51)	0% (0)	0% (0)
Pacific	C	73% (19)	27% (7)	0% (0)
	D	69% (48)	31% (22)	0% (0)
Channel	E	36% (18)	14% (7)	50%(25*)
Islands	F	56% (76)	12% (15)	33%(45*)
	G	52% (14)	22% (6)	26% (7*)
mainland	H	47% (29)	37% (23)	16%(10)
coastal California	I	100% (9)	0% (0)	0% (0)

*Note: The high number of pulses may well be associated with feeding (see Table 5)

Table 7. Mean (standard deviation) values for six parameters used to discriminate pod differences in whistles of pilot whales. F value indicates presence/absence of statistical difference as tested with a one-way analysis of variance. Pairwise comparisons were conducted using the Bonferroni test.

Region	Pod Designation	N	Duration (sec)	Start Frequency (kHz)	End Frequency (kHz)	Maximum Frquency (kHz)	Minimum Frequency (kHz)	Sweep Frequency(kHz)
Pacific	A	17	0.63(0.3)	4.21(1.1)	1.81(1.5)	4.39(0.9)	1.60(1.3)	2.79(1.2)
	B	51	0.43(0.3)	6.23(1.3)	6.96(1.9)	7.61(1.3)	5.61(1.3)	2.00(1.6)
	C	19	0.51(0.2)	5.16(1.9)	5.58(3.3)	5.99(3.3)	4.08(2.1)	1.91(2.6)
	D	48	0.44(0.3)	3.62(2.1)	2.52(2.1)	4.28(2.2)	1.84(1.5)	2.44(1.5)
	E	18	0.19(0.2)	1.44(0.7)	0.85(0.6)	1.61(0.7)	0.71(0.5)	0.89(0.8)
	F	76	0.59(0.2)	6.43(3.9)	6.30(3.8)	7.62(4.5)	5.20(2.9)	2.42(2.2)
	G	41	0.72(0.4)	2.72(0.9)	2.75(1.0)	2.92(1.1)	2.35(0.9)	0.57(0.7)
	H	29	0.36(0.1)	3.29(1.1)	5.59(1.8)	5.63(1.8)	3.35(1.0)	2.28(1.2)
	I	9	1.31(0.6)	3.86(0.5)	4.02(0.7)	4.06(0.7)	3.70(0.3)	0.36(0.5)
F value			18.53	18.84	25.86	21.06	32.09	7.38
Significant Pairwise comparisons			A-E	A-B,-E,-F,-G	A-B,-C,-F,-H,-I	A-B,-D,-E,-F	A-B,C,-F,-H,-I	A-E,-G,-I
			B-E,-F,-G	B-D,-F,-G,-H,-I	B-D,-E,-G,-I	B-C,D,-F,-G,-H	B-D,-E,-G,-H,-I	B-E,-G,-I
			C-E	C-E,-G,-H	C-D,-E	C-E,-G,	C-D,-E,	C-
			D-E,-F,-G	D-E,-F	D-E,-F,-H,-I	E-E,-F,-G	D-E,-F,-H,-I	D-E,-G,-I
			E-G,-H,-I	E-F,-G,-H,-I	E-F,-G,-H,-I	E-F,-G,-H,-I	E-F,-G,-H,-I	E-F,-H
			F-H	F-G,-H,-I	F-G,-I	F-I	F-G,-H,-I	F-G,-I
			G-H	G-I	G-H,-I	G-H,-I	G-H,-I	G-H
			H-	H-	H-I	H-I	H-	H-I
			I-	I-	I-	I-	I-	I-

Table 8. Contingency table analysis of the total number of vocalizations in three categories for three regions.

Region	Total Number of Vocalizations		
	Whistles	Fm Sweeps	Pulses
eastern tropical Pacific	135	47	3
Channel Islands	135	28	77
mainland coastal California	38	23	15

F=9.49, <.05, df = 4

Chi-Square = 75.15

Significantly Different +

Table 9. Mean (standard deviation) for six parameters measured for whistles of pilot whales. Samples were lumped into three regions to statistically test for geographic differences using a one-way analysis of variance test. Pairwise comparisons were made using the Bonferroni test.

Region	Duration (sec)	Start Frequency (kHz)	End Frequency (kHz)	Maximum Frequency (kHz)	Minimum Frequency (kHz)	Sweep Frequency (kHz)
A. eastern tropical Pacific	0.47(0.2)	4.89(2.0)	4.53(3.1)	5.80(2.5)	3.54(2.3)	2.24(1.7)
B. Channel Islands	0.58(0.3)	4.64(3.7)	4.49(3.6)	5.38(4.3)	3.4(2.8)	1.65(1.9)
C. mainland california Coast	0.59(0.5)	3.43(1.0)	5.22(1.7)	5.26(1.7)	3.43(0.9)	1.82(1.4)
F value =	4.29	4.09	0.82	0.66	0.33	3.79
Significant pairwise comparisons	A-B	A-C, B-C	-	-	-	A-B

Table 10. Dorsal color pattern type for 19 pods of pilot whales in the southern California Bight. Type A = no perceivable white, B = anterior-dorsal fin blaze plus post-dorsal saddle, and C = post-dorsal fin saddle.

Location	Number of animals	I January-March	II April-June	III July-September	IV October-December
1. Silver Canyon Catalina Island	15-25				B
2. Catalina Harbor Catalina Island	20-25		B		
	10-15		B		
3. San Clemente Island	20	B			
	15	C			
	10			B	
	8			B	
4. West of Catalina Island	10			B	
5. Isthmus Cove, Catalina Island	25	B			
6. Off Dana Point	12		B		
7. Off San Pedro Channel	12			C	
8. Off Mission Bay	4-6				B&C
9. Off Point Loma	10-12				B&C
10. North Coronado Island	15	C			
11. 31°55'N, 120°00W	25				B
12. 32°N, 119°W	25				B
13. 33°40'N, 122°50'W	15-25				B
14. 29°N, 116°W	10-20			B&C	
15. Off Anacapa, Santa Cruz	9			C	
Totals A		0	0	0	0 = 0
B		2	3	3	4 = 12

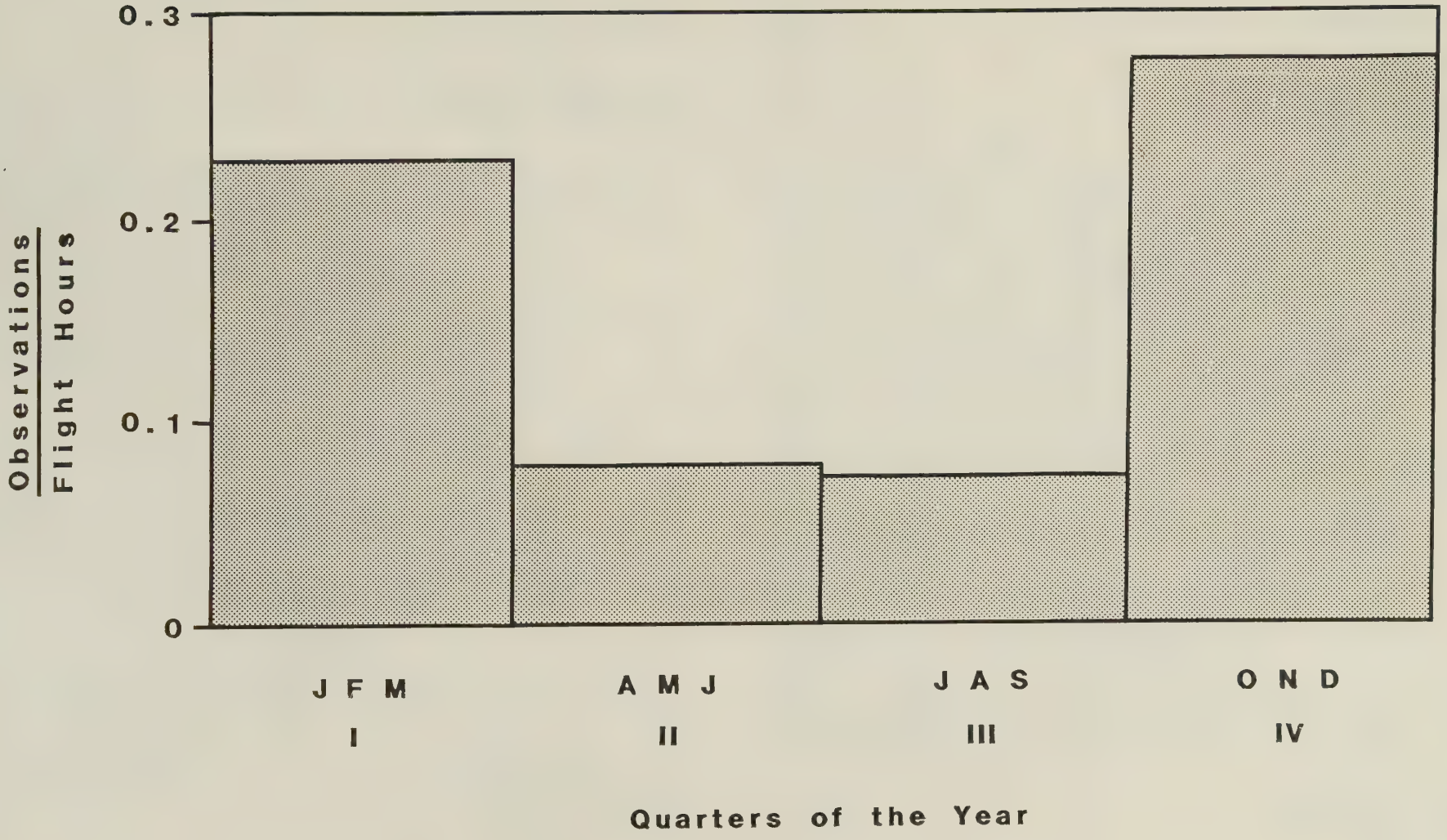
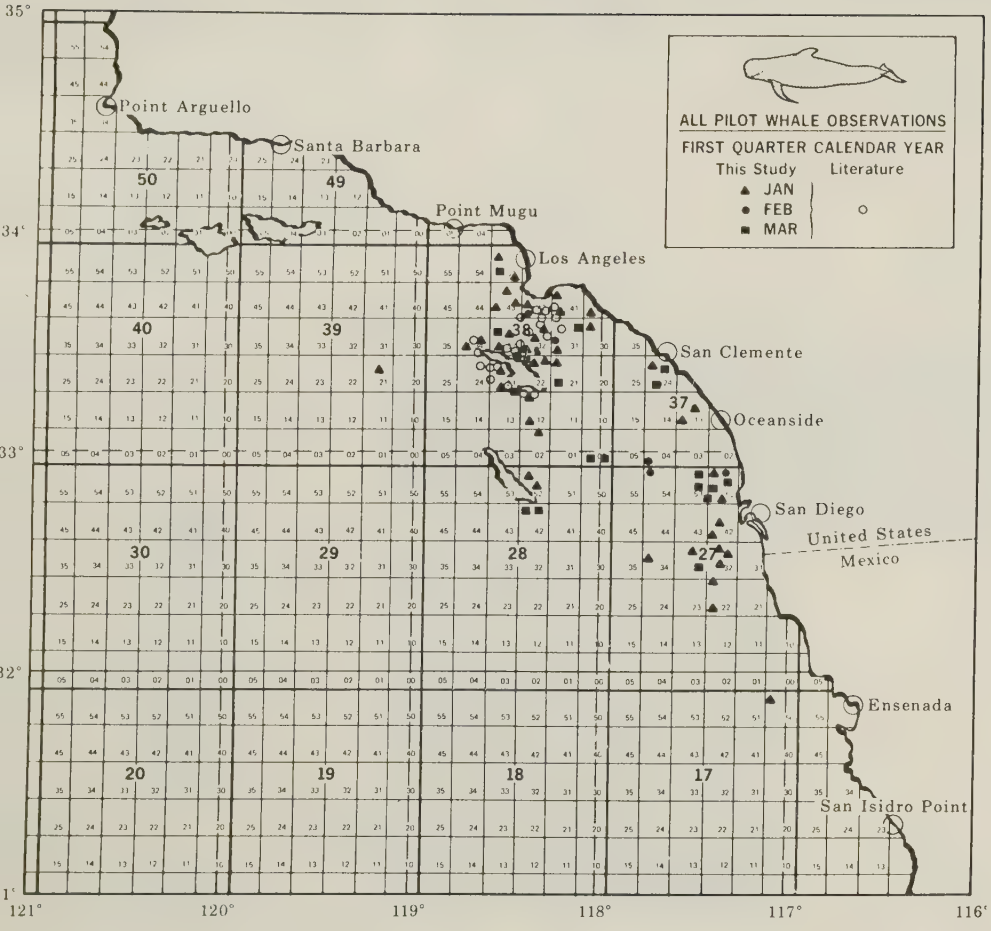


Fig. 1. Relative density of pilot whales in the Southern California Bight as function of time of year (quarter), based on aerial surveys between January 1968 and April 1976. Modified from Leatherwood, et al., 1973.



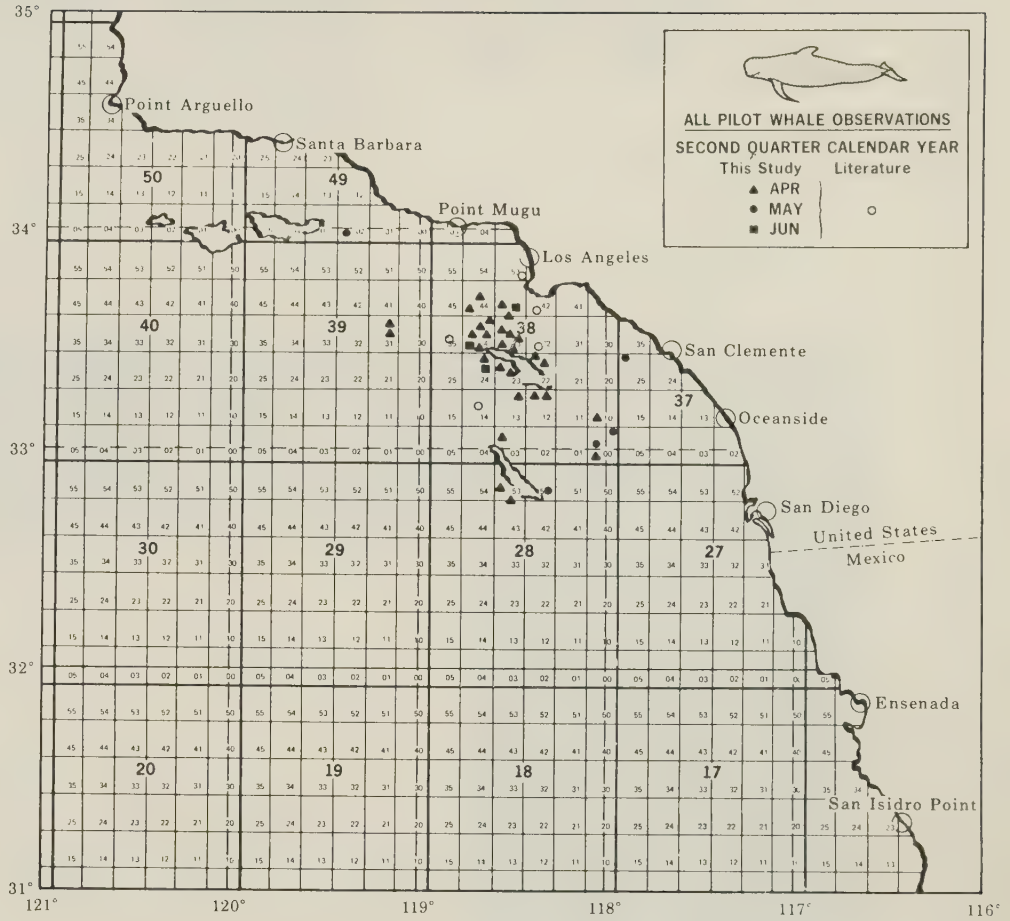
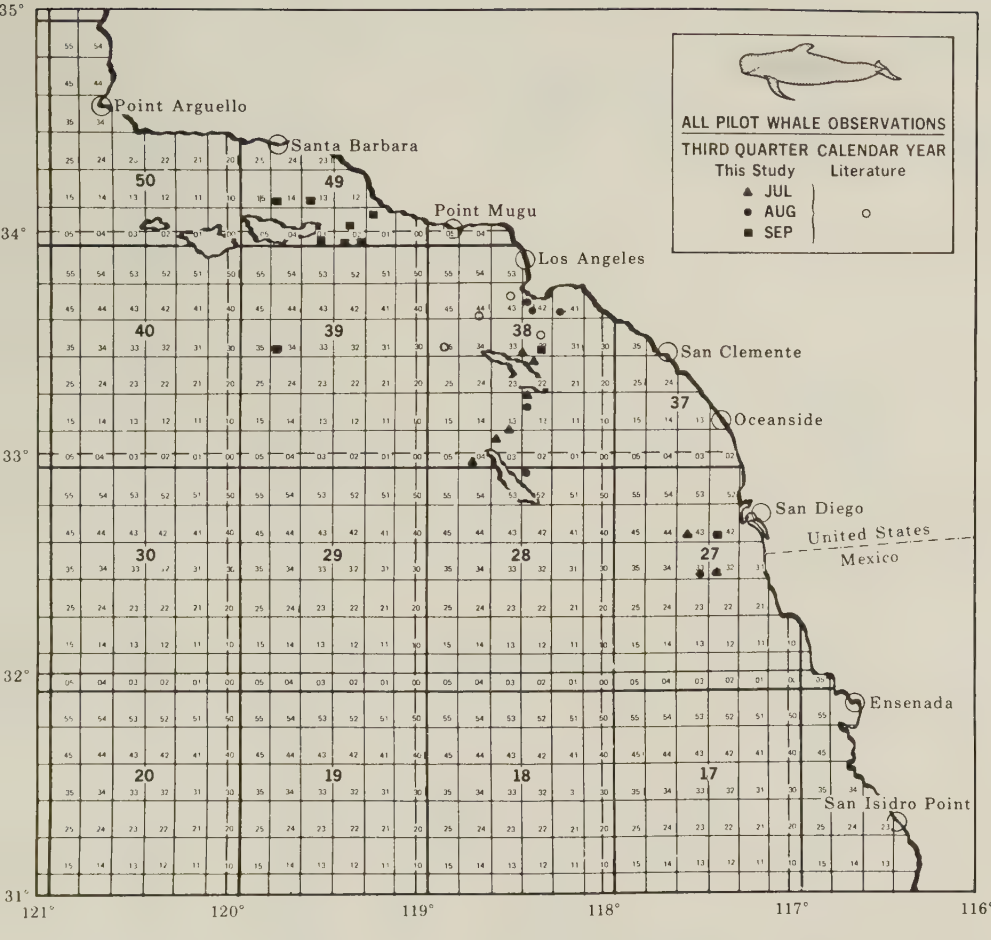


Fig. 1a. Observations of pilot whales in study area by quarter. From Leatherwood et al., 1973.



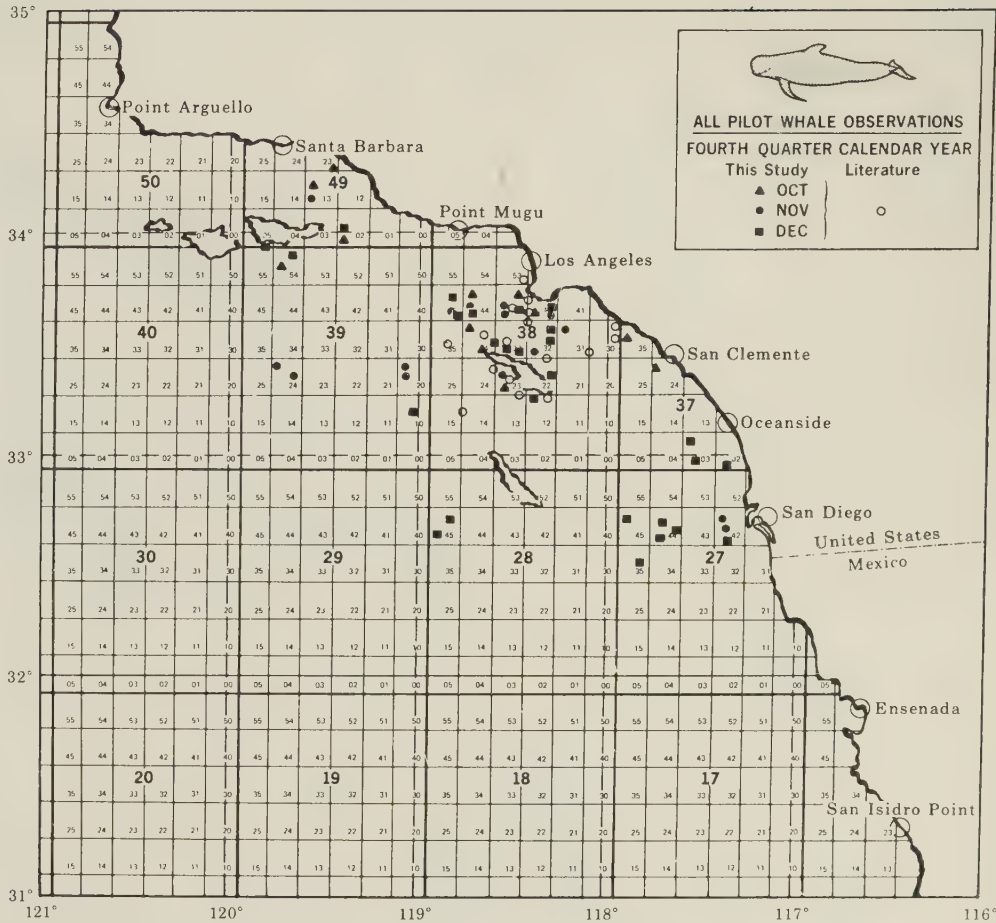


Fig. 1b. Observations of pilot whales in study area by quarter. From Leatherwood et al., 1973.

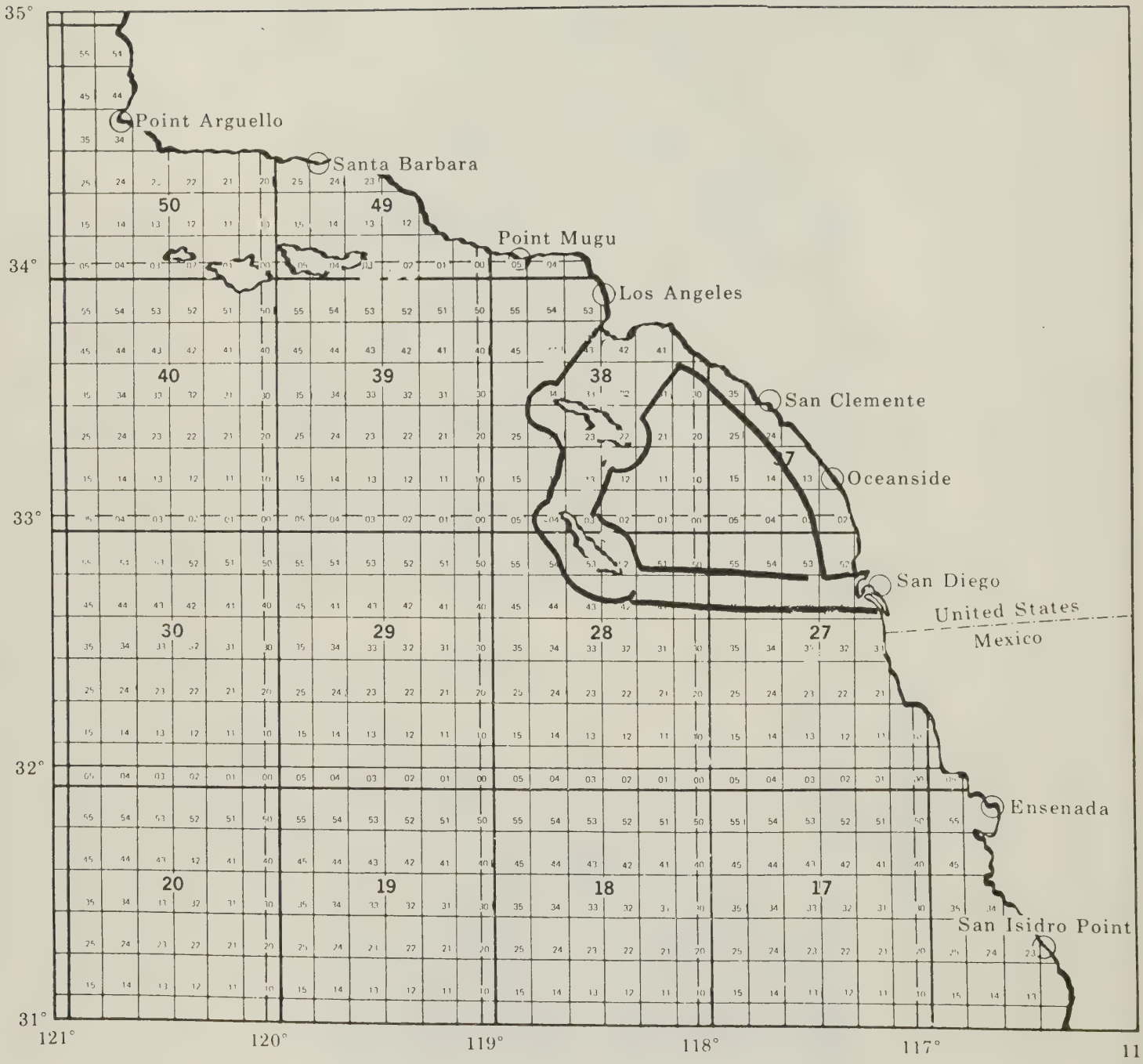


Fig. 2. The Southern California Bight, showing areas of known concentrations of pilot whales, in which aerial and boat searches were made.

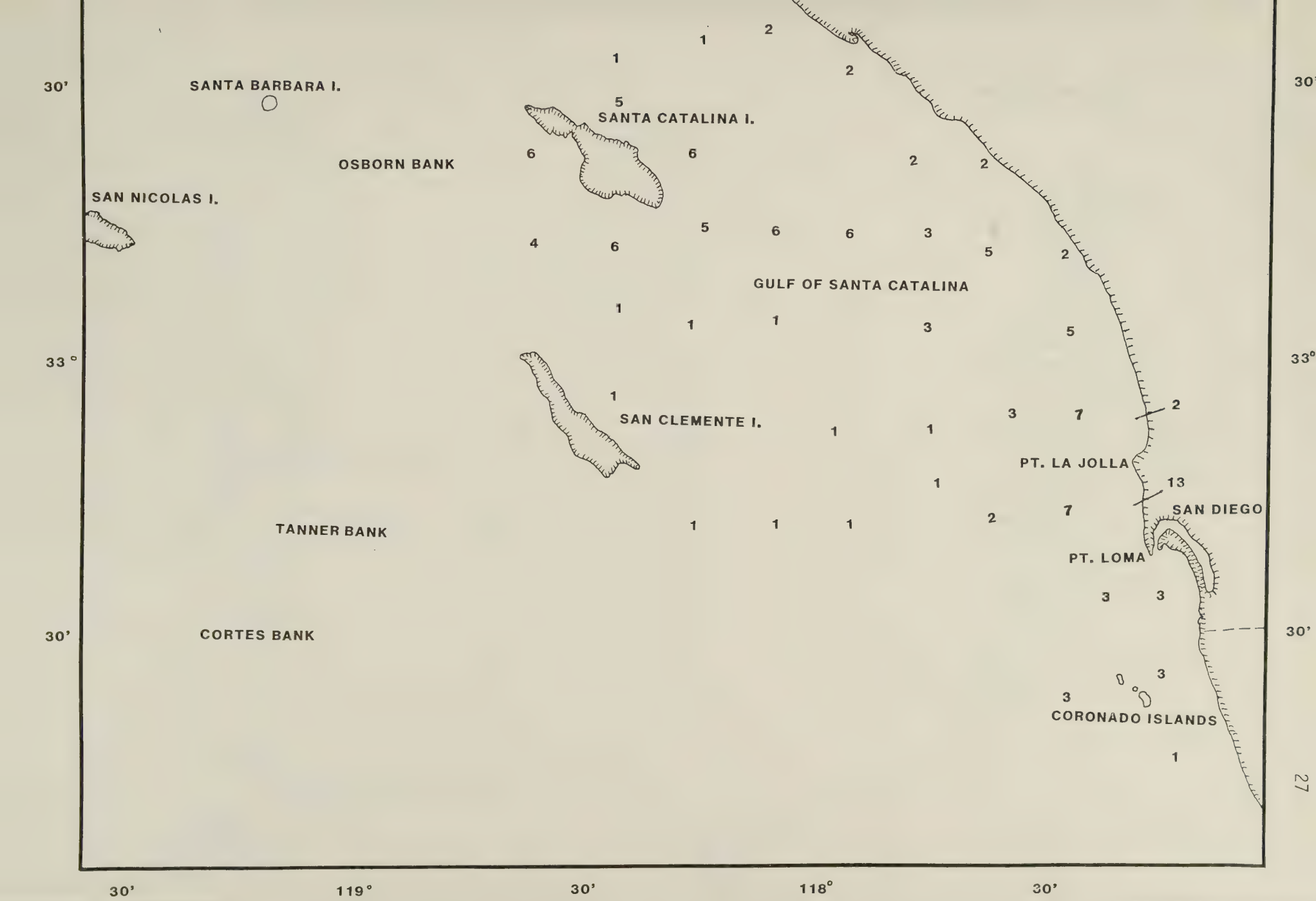


Fig. 3. Aerial survey effort. The number of times each 10x10 minute block was surveyed is given.

Fig. 4. Sightings of pilot whales during aerial (o) and vessel (●) surveys.

Fig. 5. Vessel survey effort. The number of times each 10x10 minute block was surveyed is given.

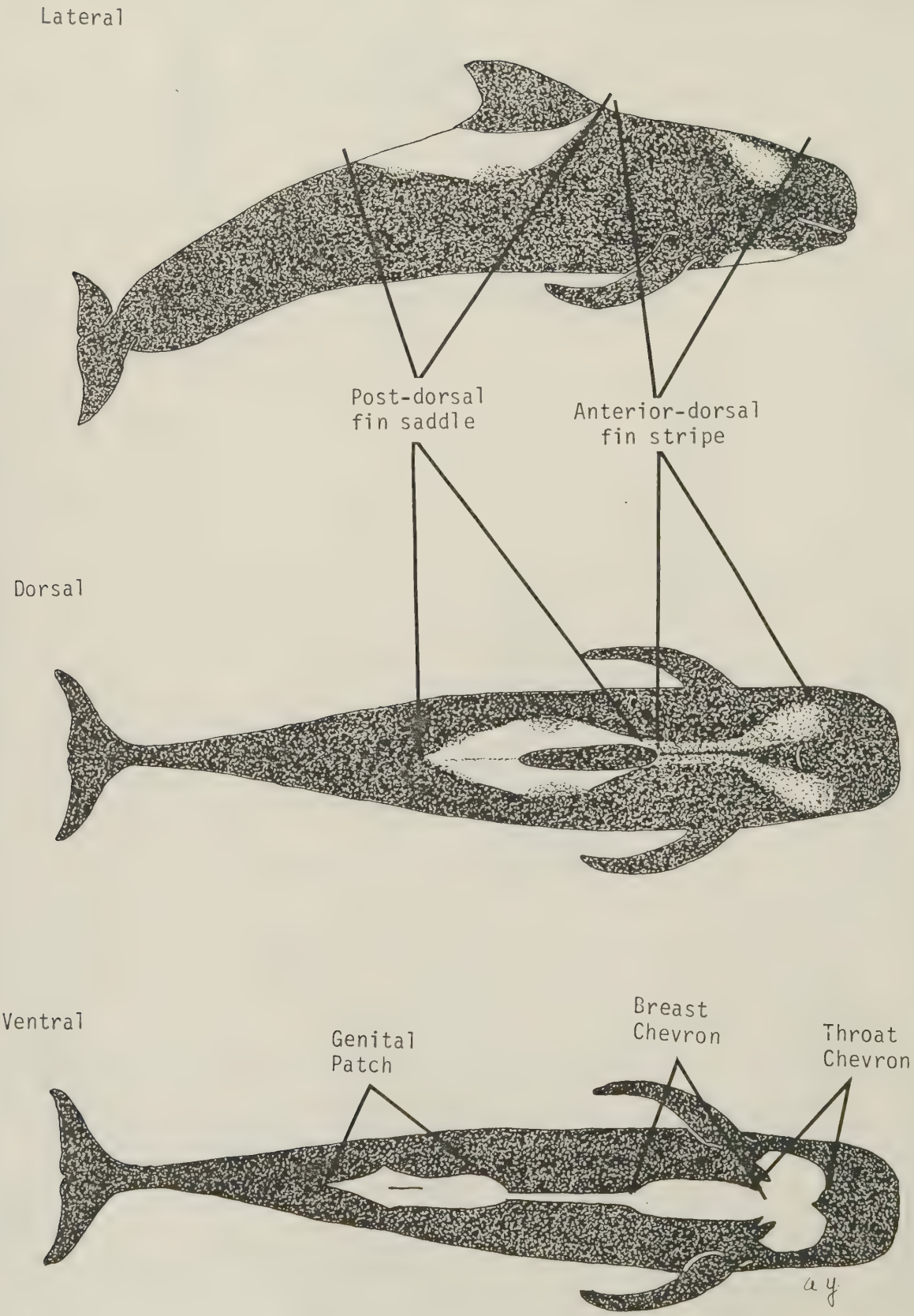


Fig. 6. Terminology used to describe the color pattern of pilot whales.

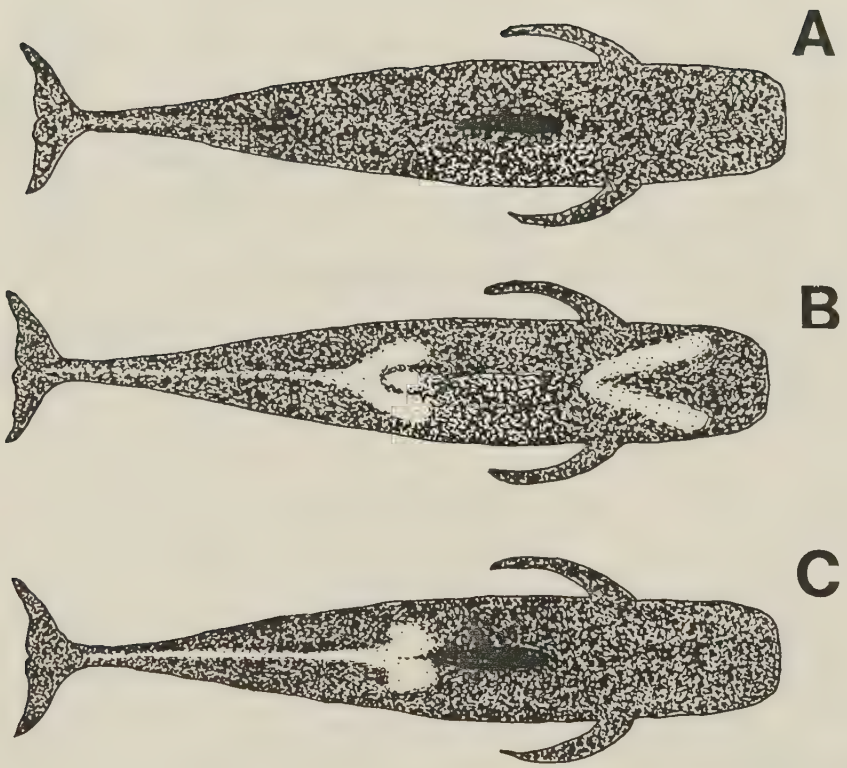
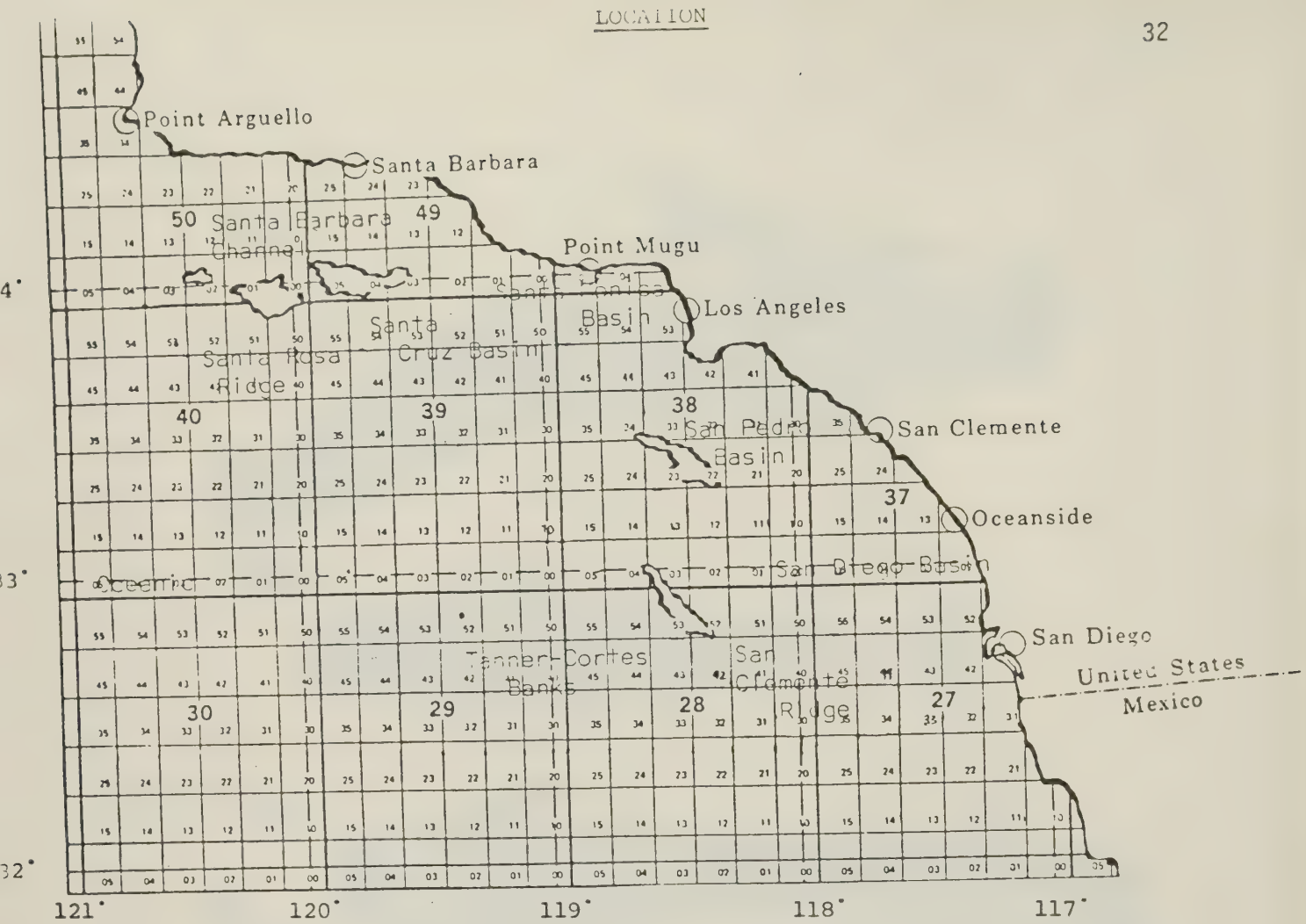


Fig. 7. Three color pattern types scored for pilot whales in this study. A. no perceivable white, B. anterior-dorsal fin stripes and post-dorsal fin saddle, and C. post-dorsal fin saddle.



COLOR PATTERN

1) Post-dorsal fin saddle: large _____ , small _____ , or none _____

2) Pectoral fin: long _____ , or short _____

3) Color pattern type: A _____ , B _____ , or C _____

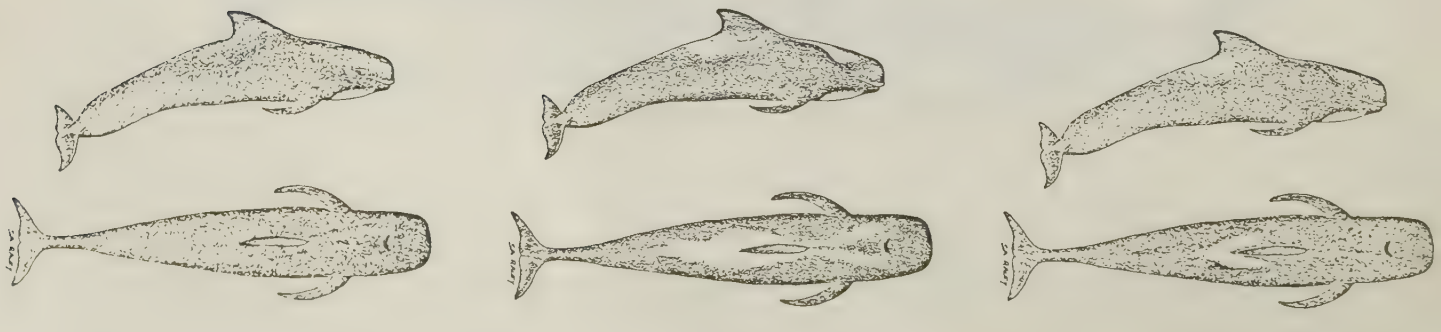
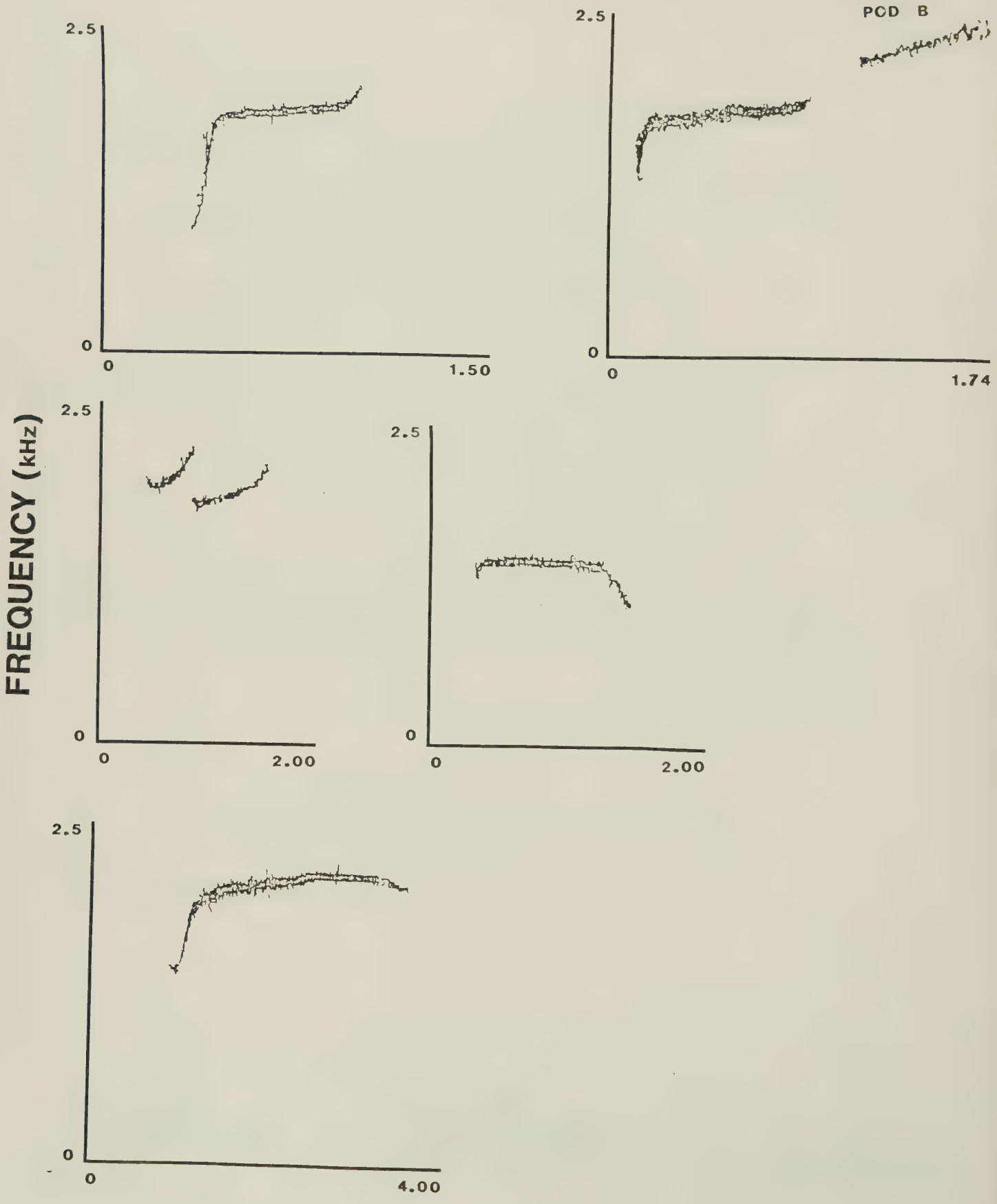


Fig. 8. The form used in the field

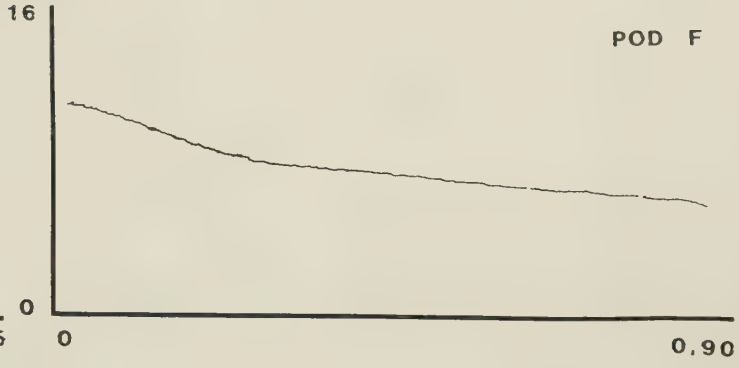
APPENDIX I

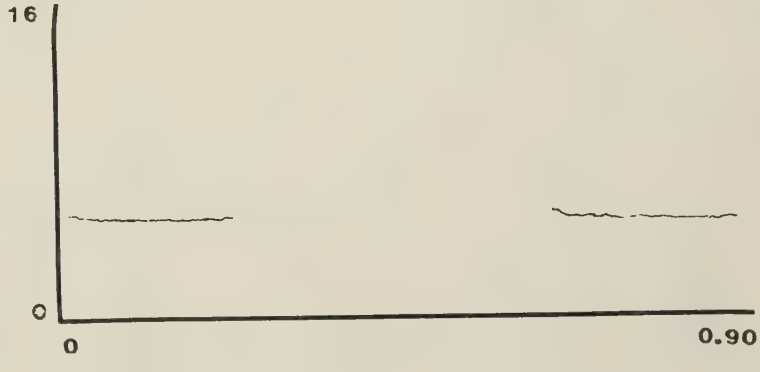
Selected sonograms from different pods of pilot whales

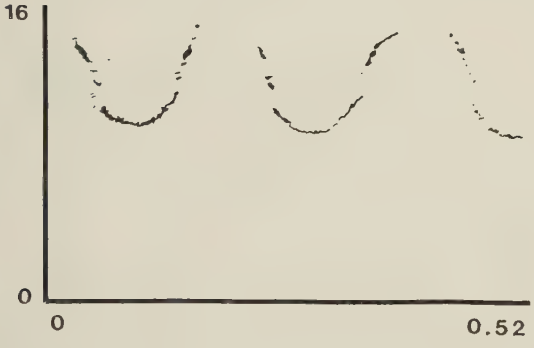
WHISTLES

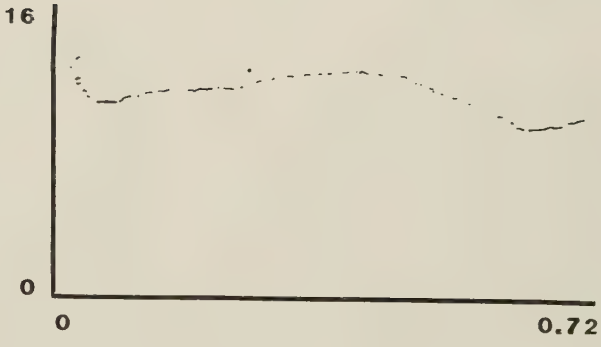

POD B
2.5
0
1.50
2.5
0
1.74
FREQUENCY (kHz)
2.5
0
2.00
2.5
0
2.00
2.5
0
4.00
TIME (Sec)

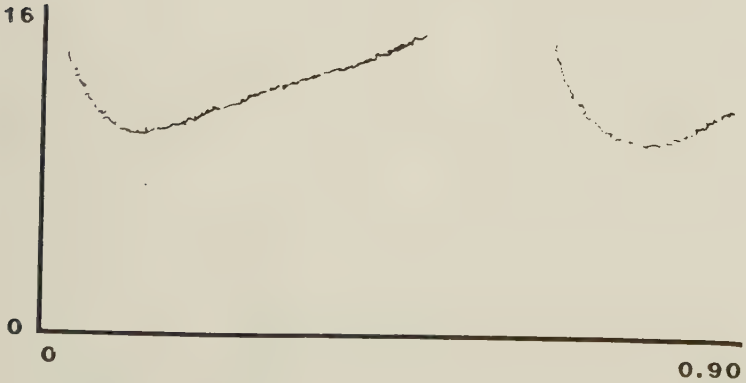
WHISTLES

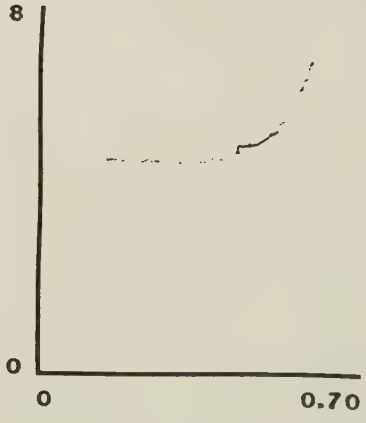










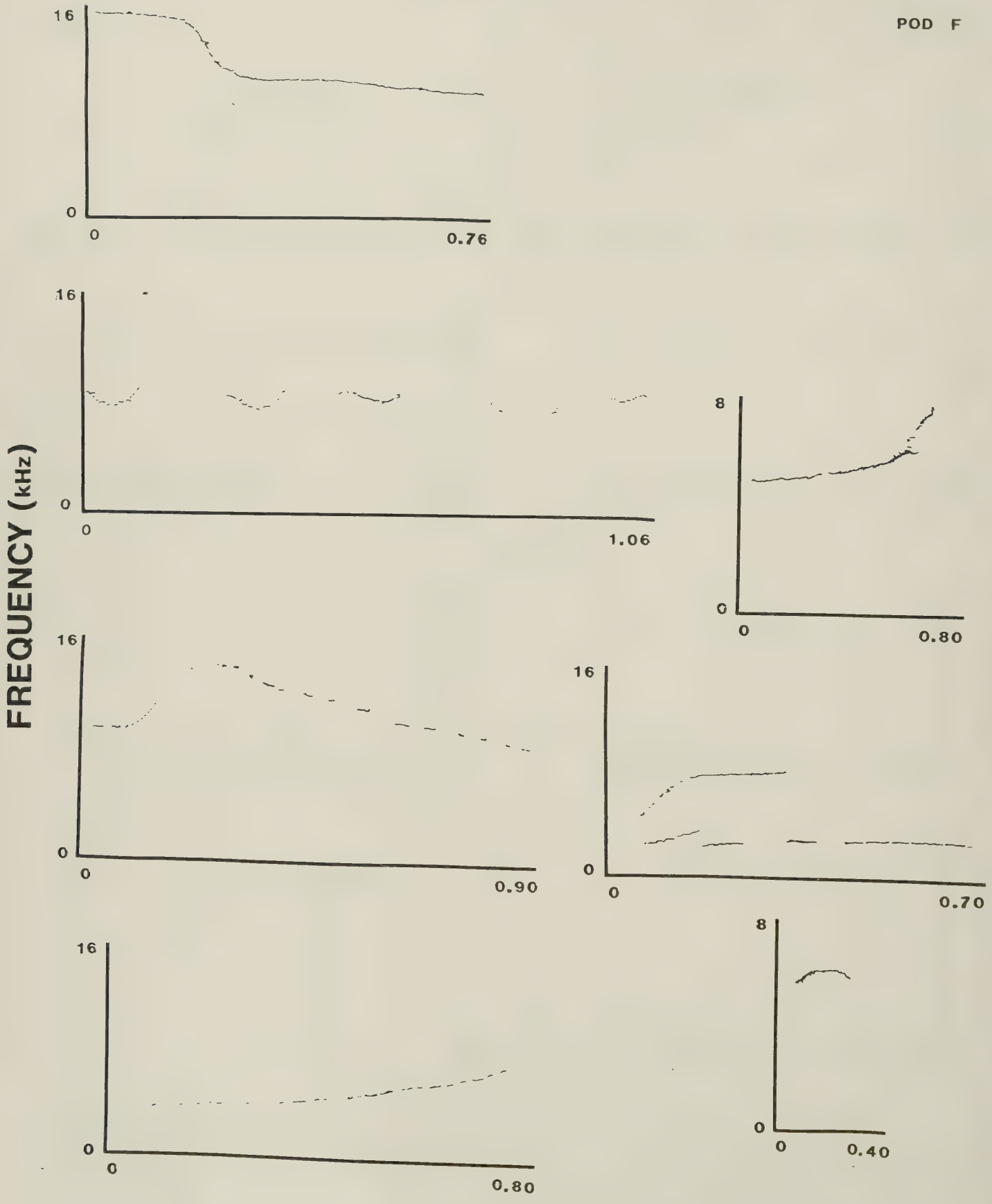


FREQUENCY (kHz)

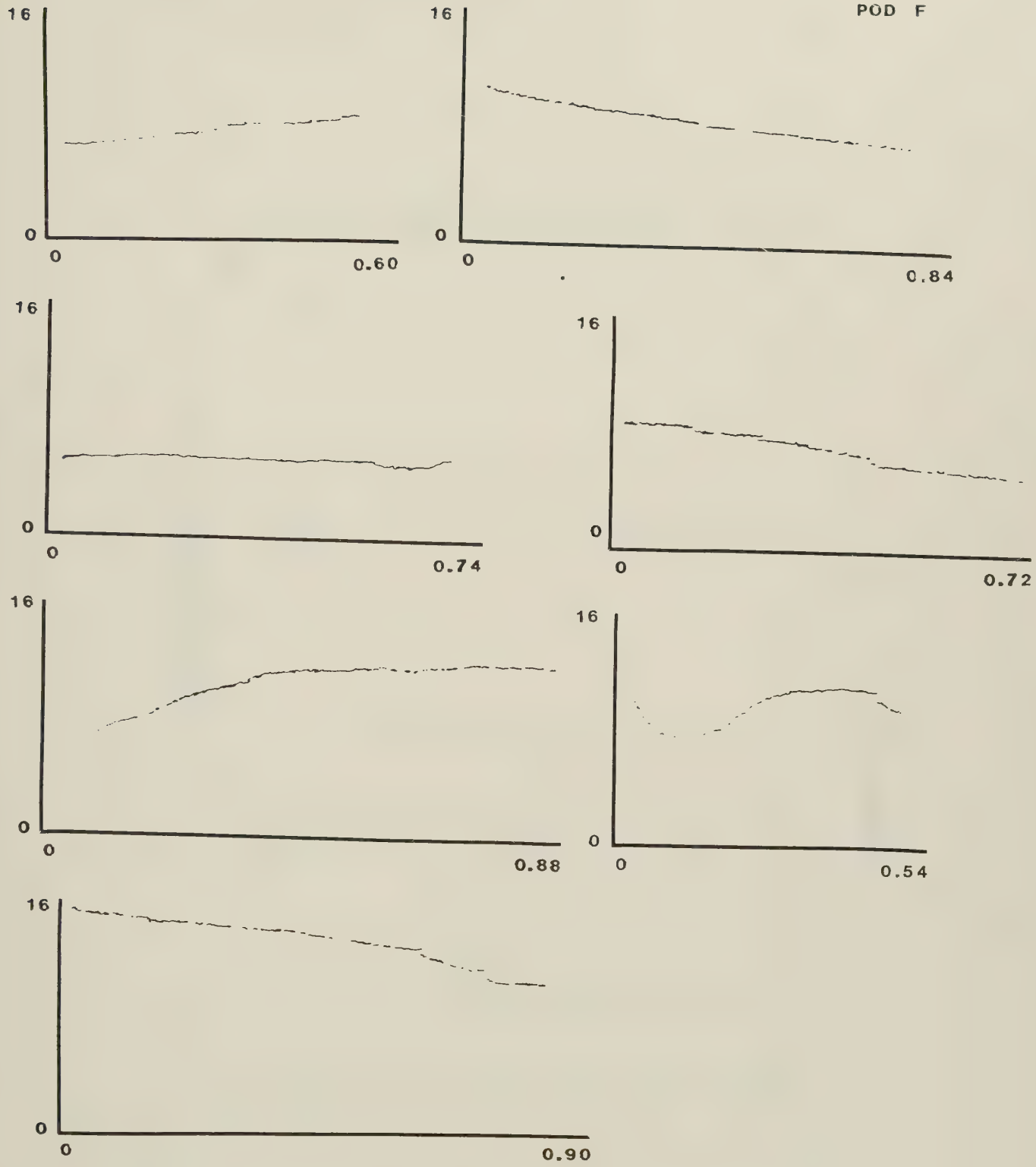
TIME (Sec)

WHISTLES

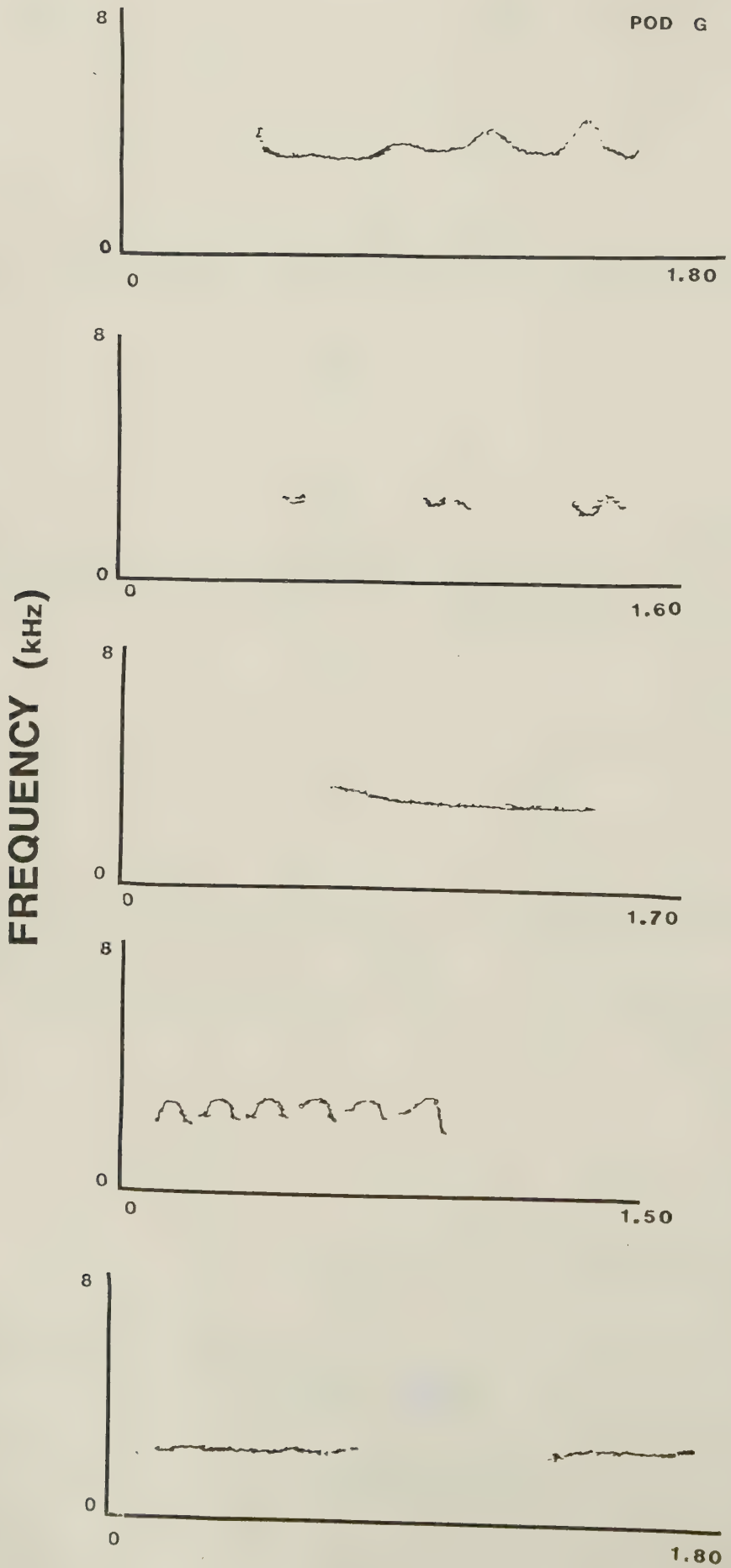
POD F



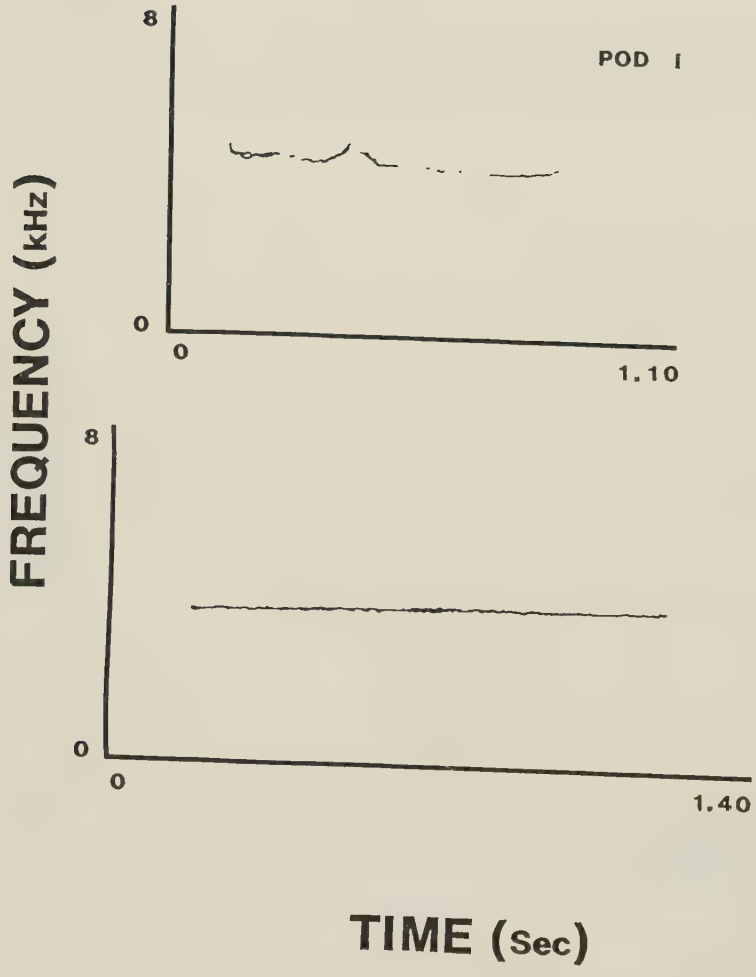
WHISTLES


POD F
16
0
0
0.60
16
0
0
0.84
16
0
0
0.74
16
0
0
0.72
16
0
0
0.88
16
0
0
0.54
16
0
0
0.90
FREQUENCY (kHz)
TIME (Sec)

WHISTLES

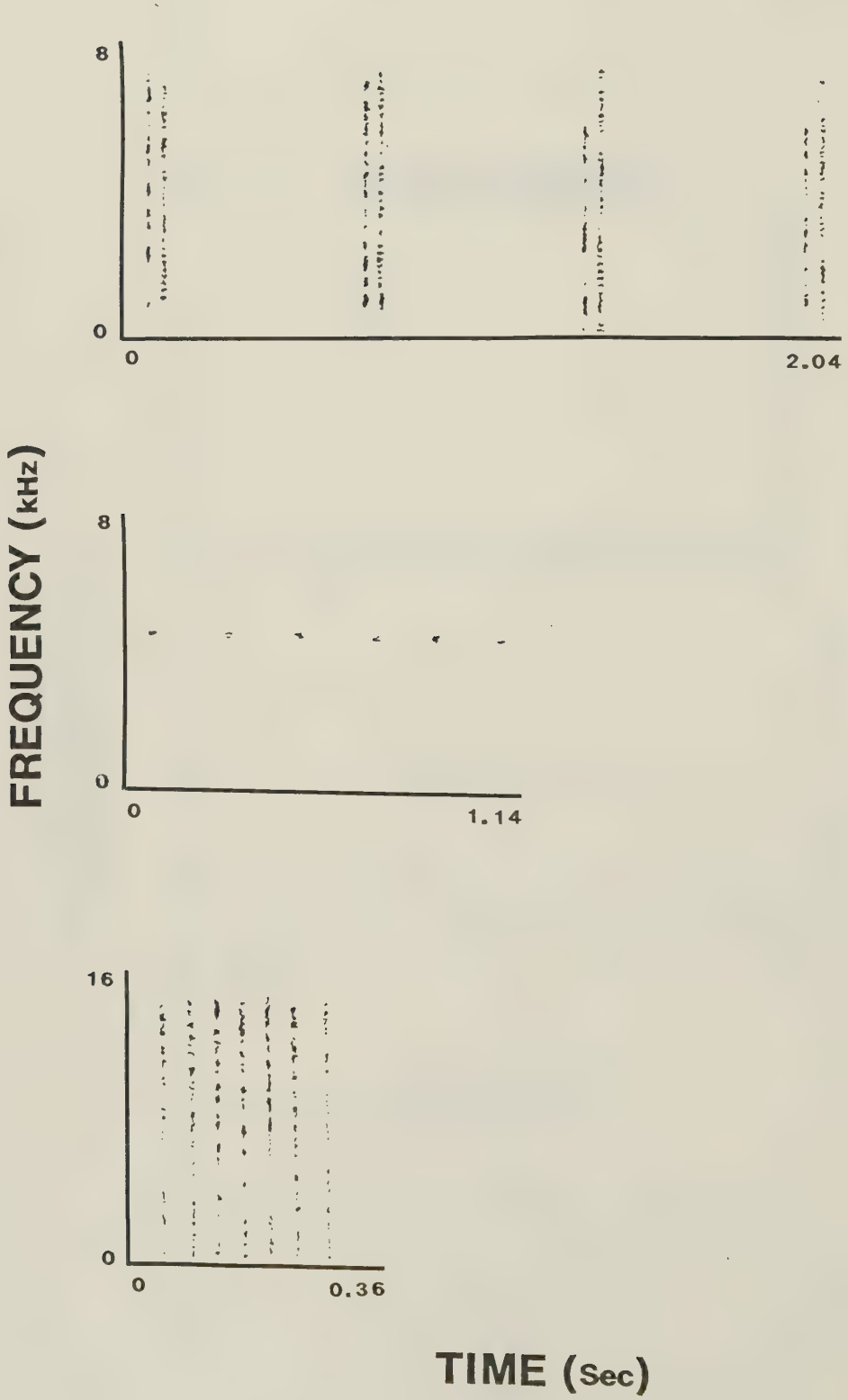


WHISTLES

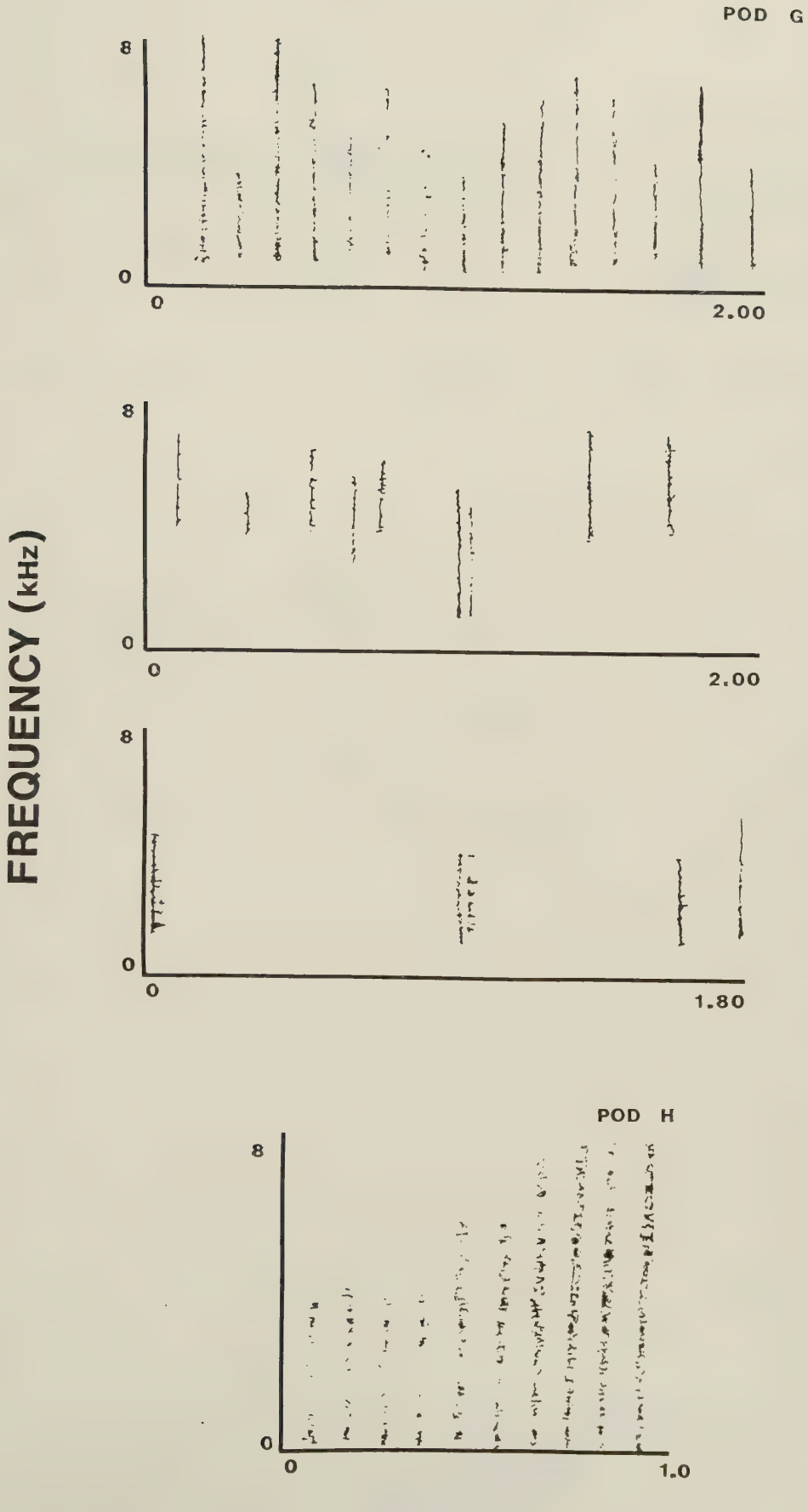


PULSES

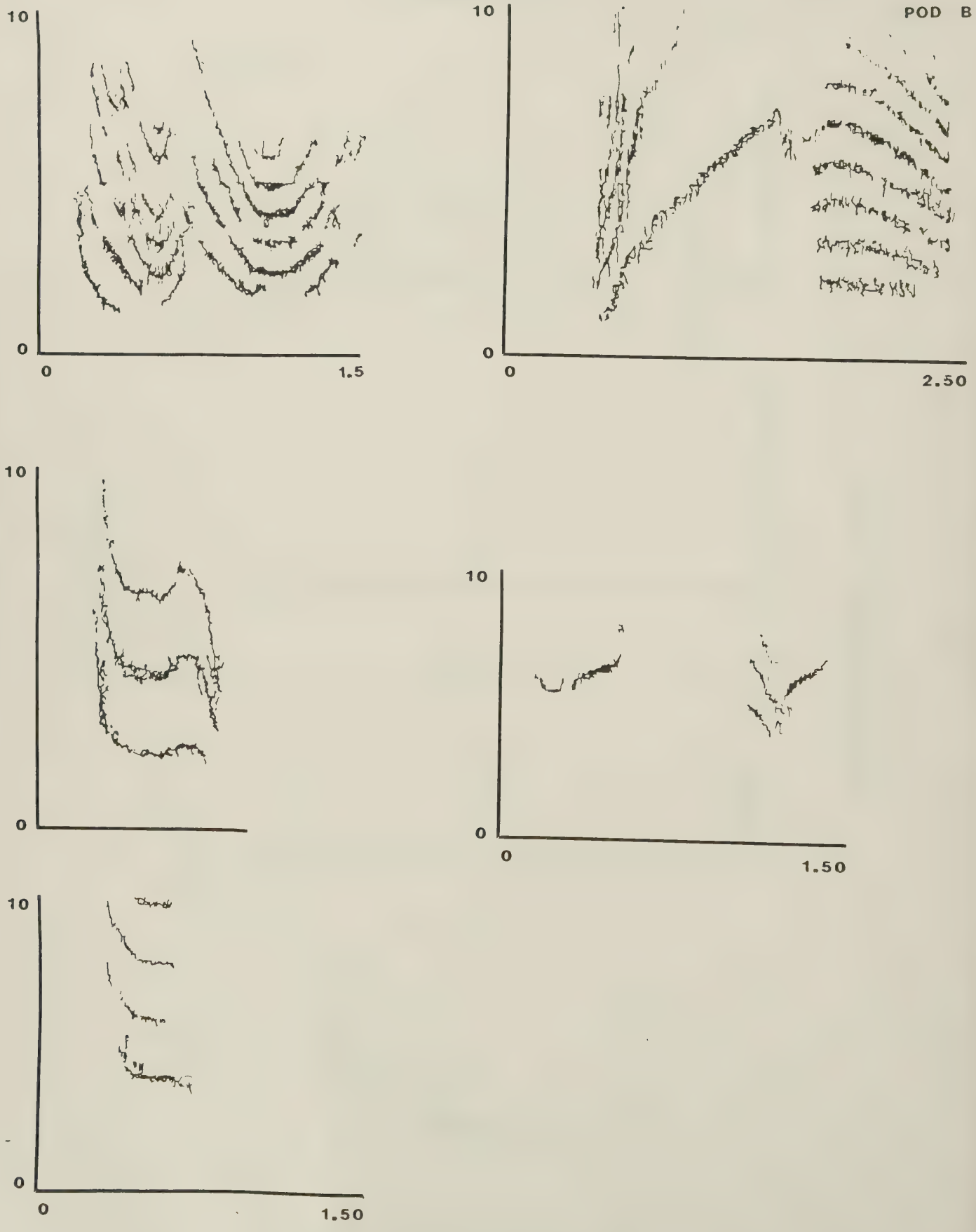
POD F



PULSES

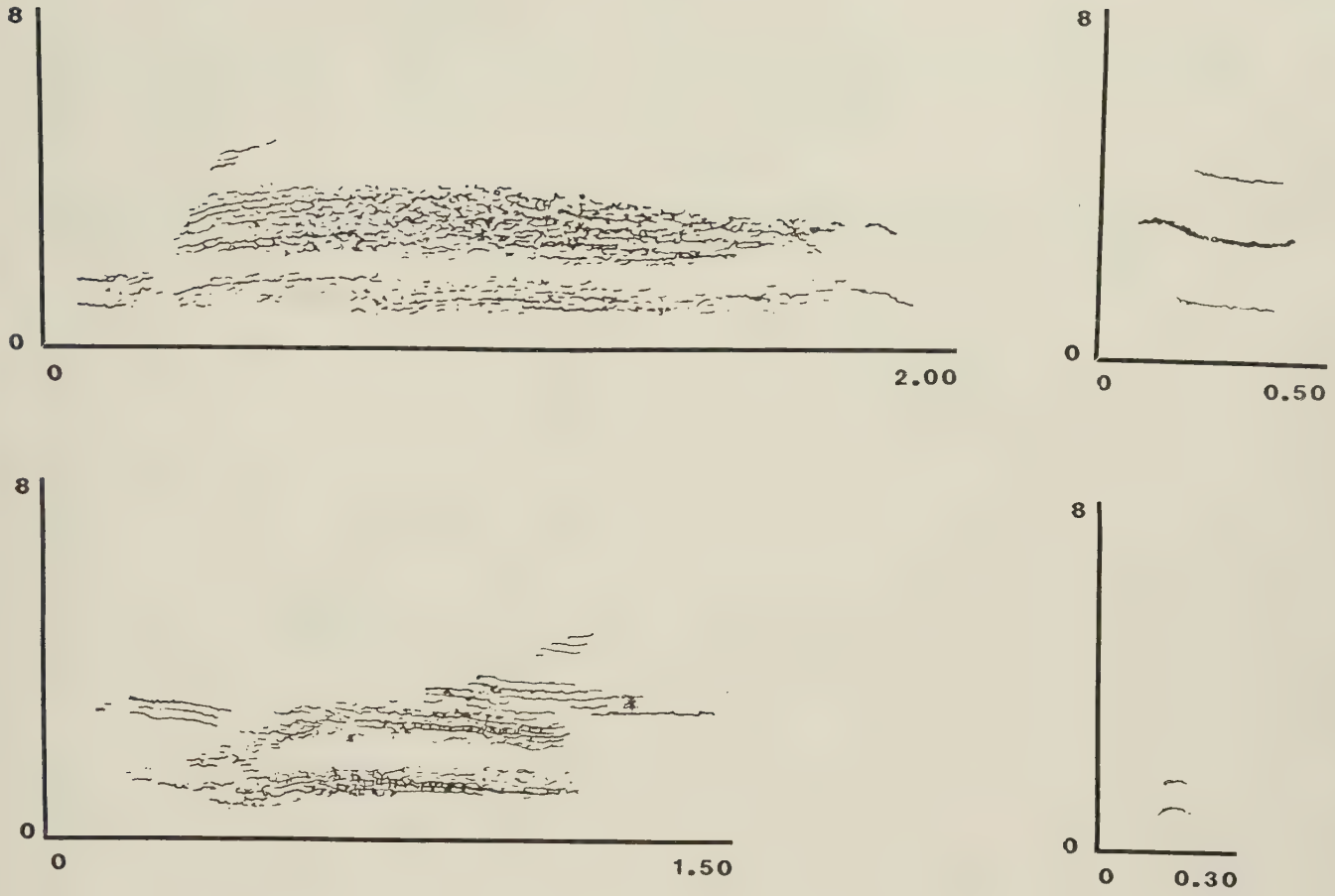

POD G
8
0
0
2.00
8
0
0
2.00
8
0
0
1.80
POD H
8
0
0
1.0
FREQUENCY (kHz)
TIME (sec.)

FREQUENCY—MODULATED SWEEPS



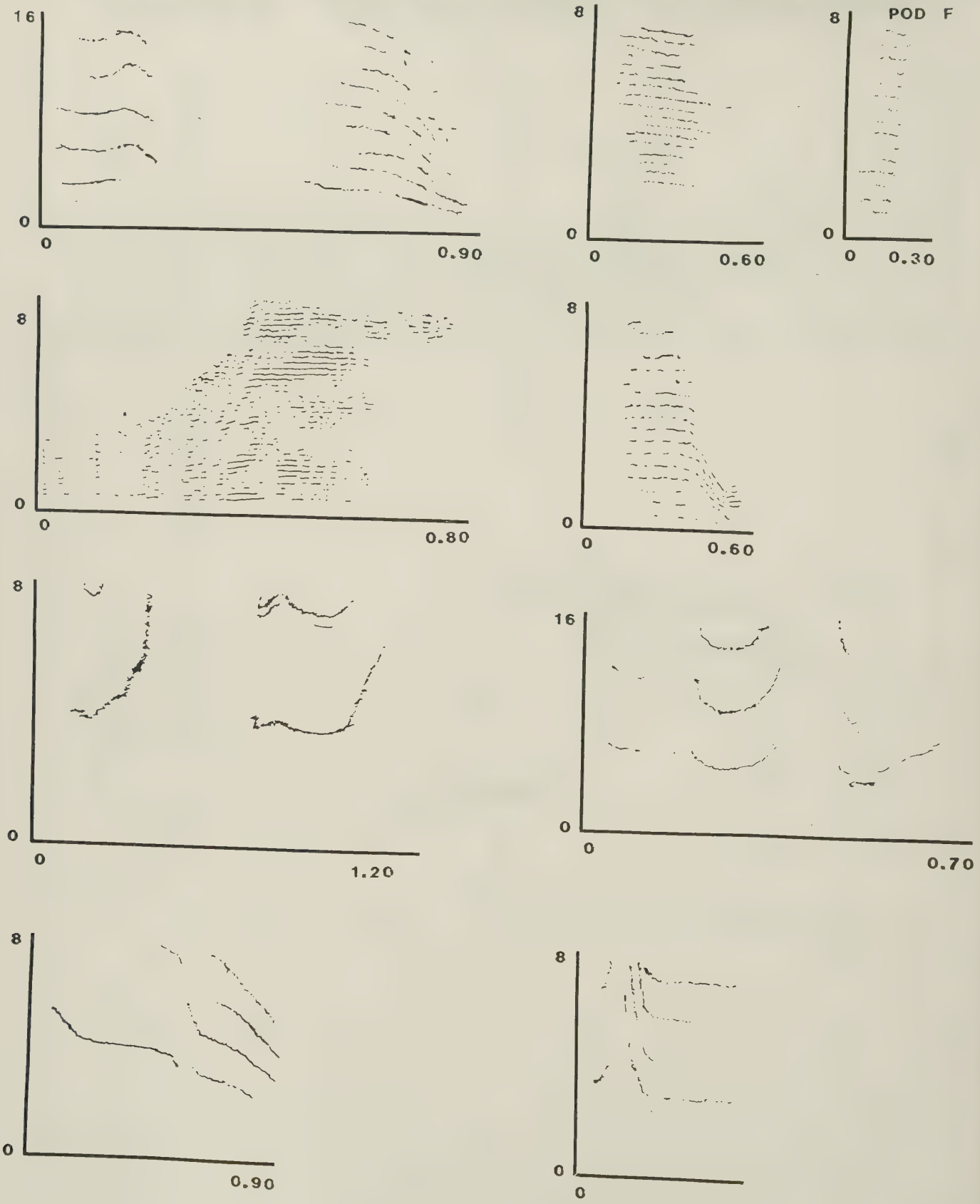
FREQUENCY—MODULATED SWEEPS

POD E

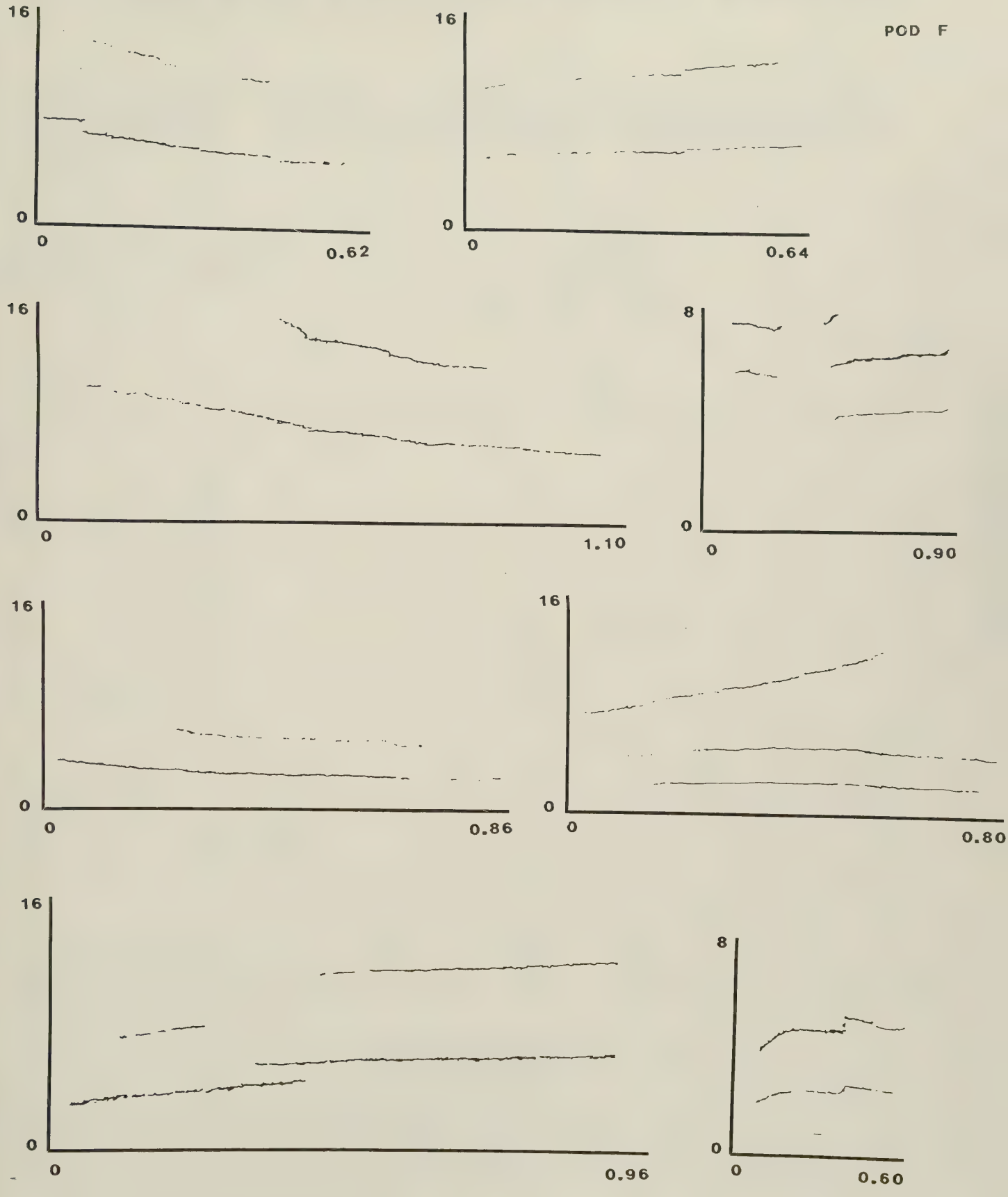


TIME (Sec)

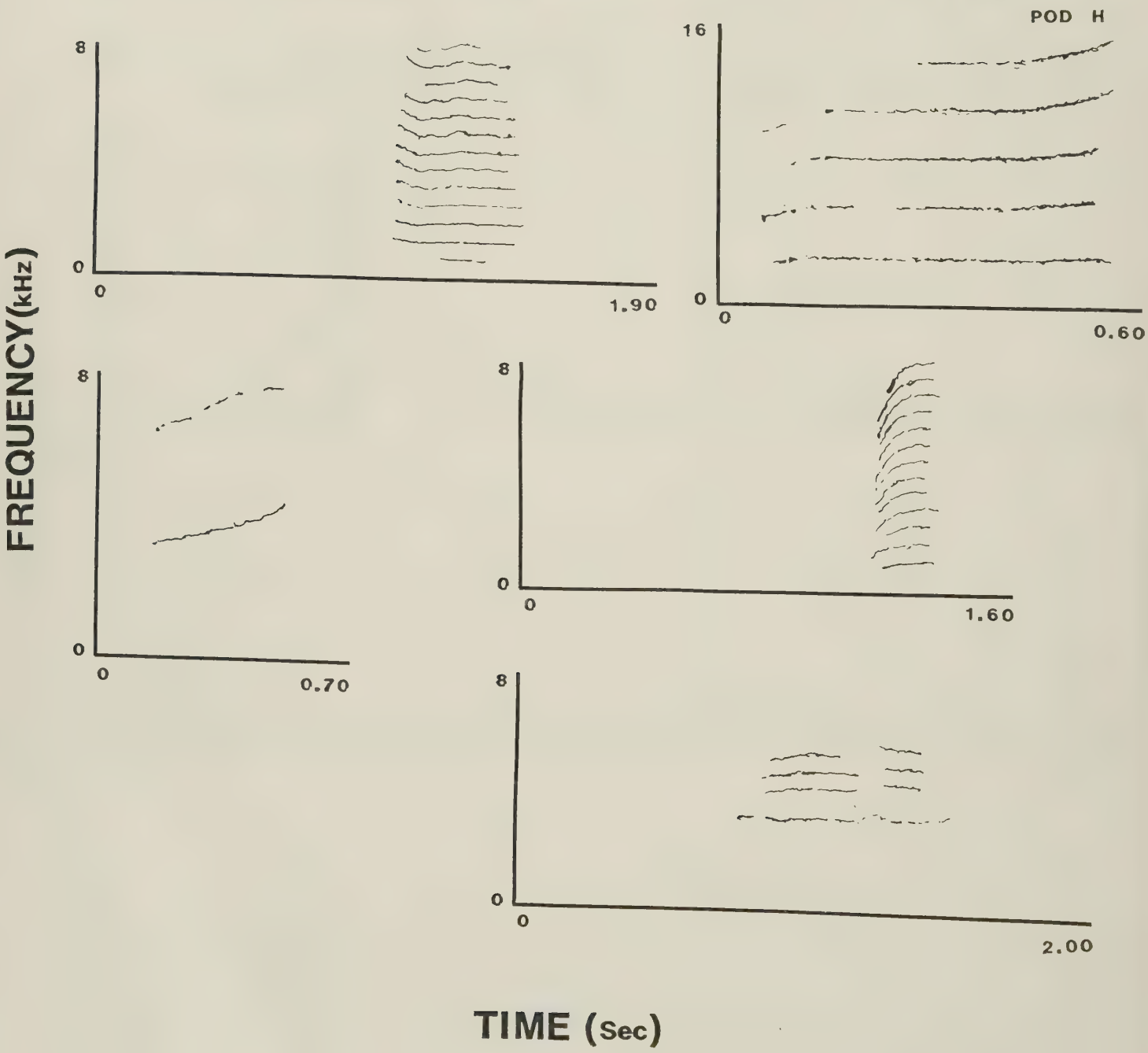
FREQUENCY—MODULATED SWEEPS



FREQUENCY—MODULATED SWEEPS

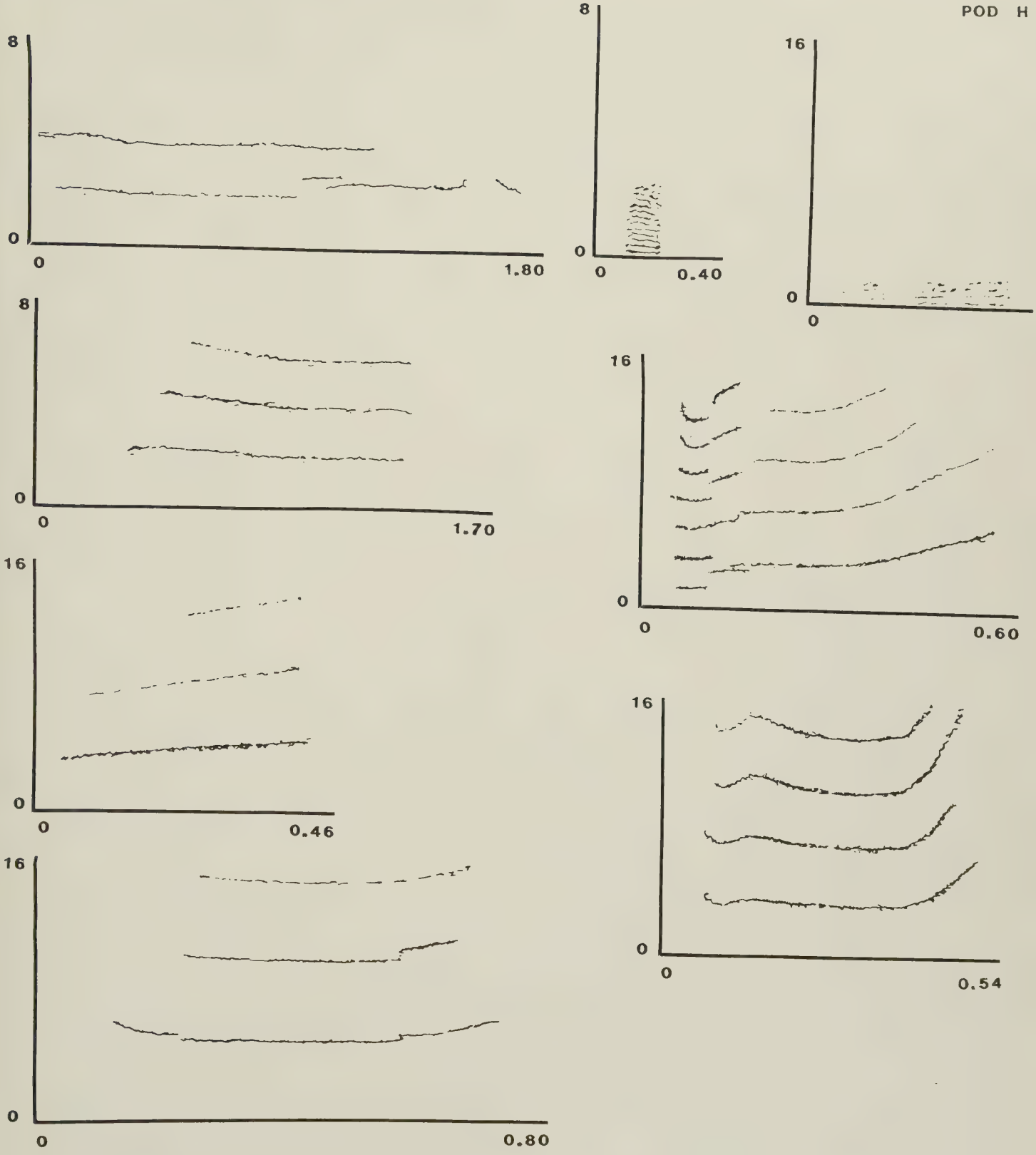


FREQUENCY—MODULATED SWEEPS



FREQUENCY—MODULATED SWEEPS

POD H



TIME (Sec)